AL.2.1988-301

CANADIANA
MAY - 6 1988

REPORT #
RRTAC 87-1

Disposal of Drilling Wastes

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

7993482

Report No. RRTAC 87-1

DISPOSAL OF DRILLING WASTES

by

L.A. LESKIW
E. REINL-DWYER
Pedology Consultants[1]

T.L. DABROWSKI
B.J. RUTHERFORD
Piteau Engineering Ltd.

H. HAMILTON
HydroQual Consultants Inc.

Prepared for

The Reclamation Research Technical Advisory Committee

of

The Land Conservation and Reclamation Council

1987

---

[1] Became Can-Ag Enterprises Ltd. on December 31, 1986

880691

STATEMENT OF OBJECTIVE

The assumptions, views, recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

Digitized by the Internet Archive
in 2015

https://archive.org/details/disposalofdrilli00lesk

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of the Environment and two Deputy Chairmen from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program, the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

Dr. G.A. Singleton, Chairman
Reclamation Research Technical Advisory Committee
Alberta Environment
14th Floor, Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta T5J 3N4

(403) 427-5815

This report may be cited as:

Leskiw, L.A., E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford, and H. Hamilton. 1987. Disposal of Drilling Wastes. Alberta Land Conservation and Reclamation Council Report #RRTAC 87-1. 210 pp.

Additional copies may be obtained from:

Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

** 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. 2 vols. L.E. Watson, R.W. Parker, and P.F. Polster. 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habitat, propagation, tolerance, and availability information are provided.

N.A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of the original report conducted in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. 2 vols. H.P. Sims and C.B. Powter. 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981 are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of recently initiated field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop reproduction.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Technical Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. 2 vols. H.P. Sims, C.B. Powter, and J.A. Campbell. 659 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. 2 vols. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 676 pp.

DESCRIPTION: This is a collection of five reports dealing with reestablishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies. An executive summary outlines the findings.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establishe a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project.
M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985.
P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta.
J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe, hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

Available from: Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
*** A $20.00 fee is charged for handling and postage.
N/A Not available for purchase but available for your perusal at the Environment Library, 14th Floor, 9820 - 106 Street, Edmonton, Alberta T5K 2J6

TABLE OF CONTENTS

Page

SUMMARY S1

1. INTRODUCTION 1

2. BACKGROUND 2

3. CHARACTERISTICS OF DRILLING WASTES 4
3.1 Major Drilling Mud Systems in Alberta 5
3.2 Characteristics of Sump Contents 7
3.3 Current Disposal Methods on Public Lands in Alberta 14

4. ENVIRONMENTS FOR DRILLING WASTE DISPOSAL IN ALBERTA 17
4.1 Soils 17
4.2 Surface Waters 17
4.3 Groundwaters 21

5. ENVIRONMENTAL EFFECTS OF DRILLING WASTE DISPOSAL 26
5.1 Effects of Drilling Waste Disposal on Soils and Plants 26
5.2 Effects of Drilling Waste Disposal on Surface Water 42
5.3 Effects of Drilling Waste Disposal on Groundwater 47

6. ASSESSMENT OF WASTE DISPOSAL GUIDELINES 57

7. MITIGATION MEASURES 63
7.1 Sampling and Analyses 63
7.2 Treatment 65
7.3 Handling of Sumps 66
7.4 Disposal Alternatives/Waste Utilization 67
7.5 Waste Management Plan 69

8. RESEARCH NEEDS 70

9. REFERENCES 74

APPENDICES

A. Characteristics of Drilling Wastes A1
B. Environment for Drilling Waste Disposal A15
C. Tolerable Levels of Waste Constituents in the Environment A29
D. Existing Alberta Guidelines A49
E. Information Gathering Through Key Contacts and Literature Searches A67
F. Glossary A69

FIELD MANUAL

TABLE OF CONTENTS

Page

LIST OF FIGURES

2.1 Major Oil and Gas Fields in Alberta 3
4.1 Generalized Groundwater Circulation 22
5.1 Surface and Subsurface Disposal 51

LIST OF TABLES

4.1 Sensitivity/Tolerance of Environmental Parameters to Surface Waste Disposal 18
4.2 Key Environmental Factors in Assessing Tolerance to Waste Disposal 19
5.1 Criteria for Evaluating Texture of Surface Material .. 33
5.2 Suitability of Sites for Sewage Sludge Disposal by Land Spreading 34
5.3 Salinity and Sodicity Criteria for Rating Soil Suitability for Revegetation 36
5.4 Maximum Permissible Cumulative Metal Loadings to Soils 36
5.5 Salt Toelrance of Various Plants 38
6.1 Criteria and Technical Implications for Subsurface, On Lease and Off Lease Disposal of Drilling Fluids 58
6.2 Criteria and Technical Implications for Subsurface Disposal 60
6.3 Additional Criteria to ID-OG75-2 for Public Lands Division Staff and Their Implications 60
6.4 Criteria for Environmentally Safe Disposal of "Liquid Waste" and "Waste Materials" Outlined in the Oil and Gas Regulations 62

ACKNOWLEDGEMENTS

This project was sponsored by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council, with financial support from the Alberta Heritage Savings Trust Fund. It was managed by the Public Lands Division of Alberta Forestry, Lands and Wildlife. The assistance of the Energy Resources Conservation Board, Alberta Environment and Alberta Forestry Lands and Wildlife was instrumental to the success of this project.

SUMMARY

Highlights of this project on drilling waste disposal are presented in this summary. Much more detail is given in the main report and appendices. A field manual has also been prepared under separate cover (Pedology Consultants, et al., 1986).

OBJECTIVES

- To identify physical and chemical problems associated with drilling waste disposal based on a literature review and consultation with various agencies.
- To assess criteria contained in existing Alberta guidelines.
- To develop, test, and demonstrate field application of a decision-making flowchart.
- To identify research needs and indicate mitigation measures for drilling waste disposal.

DRILLING WASTES

Mud Systems

The major drilling mud systems presently used in Alberta are:

Fresh Water Mud Systems - historically about 95% of all wells, where no special drilling fluid characteristics are required.

Common makeup is: water, bentonite (gel), carboxymethyl cellulose, lignosulfonates, and polymers; pH is 9-10.

Saline Water Mud Systems - used in the Foothills and in drilling in-situ bitumen wells in NE Alberta.

Common make-up is: 20,000-40,000 ppm salts (KCl or NaCl) in a water-bentonite-polymer medium, oxygen scavengers to inhibit corrosion; pH is 9.5-10.5.

Invert Mud Systems - water dispersed in diesel oil using emulsifiers, barite, organophylic clay, calcium chloride at about 300,000 ppm. These are very expensive systems and constituents are mostly recovered.

Sumps

Various portions of the drilling fluids will enter a sump unaltered, or altered due to temperature and pressure effects, presence of contaminants, and contamination by materials other than drilling fluids such as lubricants, washing compounds (information is lacking yet needed on the unidentified organics). As a result, sumps generally contain a complex mixture of organic and inorganic compounds in three distinct phases:

- Thin surficial layer of oil scum,
- Thick "fluid" phase with dissolved components and suspended solids,
- Bottom layer of "solids", sludge containing settled solids.

Horizontal variability also occurs within a sump due to release of the waste from mainly one point.

In most cases, sump volume is largely dependent on depth drilled, about 0.50 m^3 per 1 m drilled, and usually ranges from 1,000 m^3 to 10,000 m^3 per well.

Sump toxicity can be assessed by a 96 hour Trout Test or by a Microtox Test, which are tests used in ecotoxicology to assess lethality of the toxic potential of complex mixtures. In 1983-84 it was found that 60% of nearly 600 sumps tested, out of 11,000 spudded in Alberta, were toxic (ERCB, 1985). Data suggest that sump fluid toxicity is not related to well depth. Note, in this report the term "toxic" is used when referring specifically to the Trout Test or Microtox Test. Substances which are toxic to trout may be completely immobilized in a soil system. The term "noxious" is used when there may be harmful effects to one or more other organisms - plants, animals, man.

Current Disposal

The disposal on Public Lands is regulated by ERCB Guidelines (Interim Directive ID-OG75-2) which are currently under review. Presently sump fluids, other than KCl fluids, under 6,000 barrels in volume may be disposed on-lease, regardless of their chemical compositions or toxicity, given the lease is at least 300 feet from the normal high water mark of a water body. In practice, if it is known that a sump has toxic characteristics, treatment is required regardless of volume. Volumes over 6,000 barrels are disposed off-lease and have to normally meet, or if necessary be treated to meet, the following criteria:

Chloride Content	<1,000 mg/1 (if >1,000 mg/1, use a spread rate to allow off-lease disposal)
Sulfate Content	<2,000 mg/1
Total Dissolved Solids	<4,000 mg/1
pH	5.5-8.5
Trout Survival Test	1 of 2 Trout Fingerlings must survive 96 hrs.

Disposal to a subsurface formation is acceptable if that formation is not locally productive of oil and gas, and if the formation water in the disposal zone has a total dissolved solids content greater than 20,000 mg/1. If KCl drilling fluids are used a disposal plan is requested which has to be approved prior to lease construction.

The current guidelines only address the fluids part of the drilling wastes: the solids part is regulated (KCl solids) but not addressed in the guidelines. Five basic disposal methods are used at present (Lloyd, 1985):

*In pit burial
*Deep trenching or modified deep trenching and shallow trenching
Standard squeezing
Surface spreading
Deep well disposal
(* - not available in White Area)

Disposal well injection is not directly relevant to this project and is not discussed.

The first two methods have been commonly practiced in the forested areas (Green Zone) because tree clearing is minimized in order to maintain the timber base, and topography, proximity to water bodies and suitability of soils restrict the working space. The second and third methods have been commonly used on open rangeland (White Zone). The fourth method is encouraged as the preferred disposal option because degradation of materials is enhanced by microbial activity and photo-oxidation. The first two methods are now discouraged (practiced by Alberta Forestry, Lands and Wildlife, but not allowed by ERCB) because of lower degradative potential, possible formation of anaerobic decomposition products which are uncontrollable, and potential contamination of groundwater with salts or organics (Lloyd, 1985). The squeezing method, whereby a bulldozer slowly pushes fluids out of one end of the pit by pushing in fill material at the other end leaving a portion of the solids in the pit, is still accepted in Alberta (Lloyd, 1985).

ALBERTA ENVIRONMENTS

Soils

Alberta's soils vary greatly, regionally and locally, in their physical, chemical and biological properties. Drilling waste disposal has impact on soils, therefore, waste handling procedures must be tailored to the soils' sensitivity in order to minimize degradation. Soil sensitivity is governed by parent materials, physical and chemical properties of soils, biota, climate, topography (landform), and land use. Table 1 provides a generalized breakdown of these parameters along gradients representing low to high environmental sensitivity/high to low tolerance for surface waste disposal. Note that each parameter must be examined separately because this Table does not allow a systems approach at the outset as shown below.

SYSTEMS COMPONENT	SENSITIVITY
System 1:	
Till	low
Chernozemic	low
Vegetation for immediate consumption	high
Moist climate	low
High productivity, dense population	high
System 2:	
Organic	high
Organic	high
Vegetation not entering food chain	low
Cold	high
Wildlands	low

Nevertheless, rating of each parameter allows one to find the best combination (i.e. low sensitivities) of conditions and to consider the most attractive mitigation measures. For example, changing vegetation cover is easy; changing parent material is impractical. This leads to an understanding of the total system and ultimately appropriate management practices can be planned and implemented to minimize or avoid environmental damage.

Table 1. Sensitivity/Tolerance of Environmental Parameters to Surface Waste Disposal.

◄---------------------- SENSITIVITY TO/TOLERANCE FOR SURFACE WASTE DISPOSAL ----------------------►

Low Sensitivity/ High Tolerance			High Sensitivity/ Low Tolerance
PARENT MATERIALS			
Fluvial-Lacustrine Till (Plains) Lacustro-till	Fluvial Lacustrine Bedrock (plains)	Fluvial-Eolian Till (Foothills and Mountains) Bedrock (Foothills and Mountains)	Eolian Organic
SOILS			
Black Chernozemic Dark Gray Chernozemic and Dark Gray Luvisolic	Dark Brown Chernozemic Gray Luvisolic	Brown Chernozemic Brunisolic	Solonetzic Gleysolic Regosolic (floodplains) Organic
VEGETATION			
High salt tolerance Vegetation not for human consumption or entering the food chain	Medium salt tolerance Vegetation entering food chain	Low salt tolerance	Low salt tolerance Vegetation for immediate human consumption
CLIMATE			
Warm, moist (Black Soil Zone) (Dark Gray Soil Zone)	(Dark Brown Soil Zone) (Gray Soil Zone)	(Brown Soil Zone)	Droughty, windy, cold (SE Alberta, high elevations) (Undifferentiated Mountain Complex)
TOPOGRAPHY/LANDFORM			
Level to gently sloping uplands	Moderate slopes	Steep slopes	Very steep slopes Floodplains Dunes
LAND USE/POPULATION DENSITY			
Wildlands Rangelands Sparse population	Low productivity forests and agriculture	High productivity forests and agriculture	Crops for human consumption Dense population

Surface Waters

Salinity levels of surface water bodies in Alberta are generally low (EC <2 mS/cm) and dominated by calcium carbonate. Saline sloughs and small lakes occur mainly within a north-south band 50 to 100 km wide from around Vegreville to the Brooks area, corresponding to the belt of Solonetzic soils. Sodium and sulphate are often the major constituents.

Lakes and rivers in Alberta are alkaline and pH levels range from approximately 7.0 to 8.5. Minimum values occur under ice in the winter; maximum levels are recorded in late summer or fall.

Heavy metals in all systems are usually near the lower limit of analytical detection. This is a function of high pH which favours precipitation of the heavy metals and their adsorption to particulates.

Levels of organic carbon, nitrogen and phosphorus vary and tend to be higher in the prairie and parkland relative to the foothill and mountain drainage systems. During the open water season ammonia levels are low due to nitrification and uptake by aquatic plants and algae. The exceptions are sites immediately adjacent to point source municipal effluents. Under ice, levels of ammonia are often elevated due to decay of organic material and reduced rates of nitrification and uptake by plants.

Despite these general patterns water quality in water bodies can vary markedly over small distances, a reflection of their relative size and different watershed/runoff characteristics.

Groundwaters

There is a wide range in both the quantity and quality of groundwater available in Alberta, resulting from the complex interplay of topography, geology and precipitation. Groundwater is recharged in topographically high areas through the infiltration of precipitation and surface water; it will then flow through aquifers and be discharged in topographically low areas. The amount of recharge is dependent on many factors including precipitation, evapotranspiration, surface runoff and infiltration rates.

In general, the groundwater surface (water table) is a subdued replica of the topography. Local groundwater flow is relatively shallow and interactive with nearby topographic features such as rivers, marshes and hills: regional groundwater flow is relatively deep and unaffected by local topography.

Bedrock Environments

The predominant bedrock region is the Interior Plains. The bedrock is flat to gently dipping sedimentary strata that increase in thickness towards the west. Aquifers within this region are typically sandstone and coal, which have been fractured. Water quality of these aquifers is poor.

Strata in the Cordilleran Region (mountains and foothills) are steeply dipping and are mainly sedimentary. Bedrock aquifers in this area are commonly sandstone or limestone. Water quality in deeper aquifers is usually poor and not suitable for human consumption.

Bedrock strata in the northeast corner of the province are varied in composition and age. Devonian and cretaceous aquifers in this area are flat dipping and comparatively uniform in thickness. With the exception of the subcrop or outcrop areas, groundwater contained in these deposits has high mineralization and is not suitable for human consumption.

Surficial Environments

Surficial deposits in Alberta are largely related to glacial activity. Till deposits up to 100 m thick are of limited hydrogeological importance even though they may include thin, discontinuous layers of higher hydraulic conductivity sand and gravel.

The lacustrine deposits are usually homogeneous and consist of very low hydraulic conductivity silt and clay about 10-20 m thick. Such deposits can be considered as aquitards that will not transmit water.

Throughout the province, and particularly in the northeast, glacial outwash deposits of sand and gravel are present. Such materials are water-sorted by glacial meltwater and surface water, and are therefore potentially good aquifers. These deposits, although typically of variable extent and thickness, are a major source of domestic water.

A very important surficial aquifer, which is not directly related to glacial activity, is the buried valley aquifer. Such aquifers contain high hydraulic conductivity sand and gravel deposits (usually less than 100 m below ground surface) and are the highest yielding aquifers found in the province. As such, they represent an important supply of domestic water. Post-glacial rivers and streams tend to parallel the course of pre-glacial valleys in the foothills where such valleys are more deeply incised. In the prairie regions, however, present day river and stream courses frequently have no relationship to pre-glacial valleys.

Hydrochemistry

The hydrochemistry of groundwater is primarily dependent on its age and type of deposits through which the water flows. Certain groundwater types can often be associated with particular geologic deposits through which the water has moved, such as till or shale. In general, the longer the water has been circulating below ground surface, the greater the mineralization.

Dissolved organics are present in natural groundwater but concentrations are much lower than that of the dissolved inorganic matter. Although some dissolved organic substances are noxious at concentrations considerably lower than for dissolved inorganics, naturally occurring dissolved organics seldom make water non-potable.

ENVIRONMENTAL EFFECTS

Effects on Soils

Drilling waste disposal impact on physical and chemical properties of soils, and plants is dependent on the disposal method, waste characteristics, and the environment.

Effects of the four major disposal methods on soil physical properties are related to mixing and compaction of the soil.

Burying and trenching affect a relatively small area, but lead to:

- change (degradation) of structure
- change in texture (dependent on stratification)
- increased bulk density
- reduced infiltration and permeability
- reduced aeration

Squeezing and spreading require a large area. These methods have similar but likely less drastic effects than burying and trenching; textural redistribution may occur, and texture becomes finer if clays are added. Clods of mud may form resulting in poor soil tilth. Spreading permits these effects to be more homogeneous and controllable, and therefore potentially less severe, than under the other methods. Biological decomposition of organic constituents is enhanced under warm, moist and aerated soil conditions.

In general, the effects are less negative, or even positive, on sandy soils as compared to clayey soils, provided that the wastes are not noxious, because if applied to permeable soils groundwater contamination could result.

The magnitude of the effects differ with climate and soil type. They become less damaging with increased permeability (sandier textures) and increased net downward movement of water in soil (humid climate).

The fate and effects of organic constituents in drilling wastes is least understood. In general the decomposition of recalcitrant organic additives and their degradation products has not been researched in depth.

Effects on Plants

Drilling waste disposal indirectly affects plants which react to changes in the soil environment. Changes in physical characteristics such as soil structure and bulk density, within the root zone/above the buried material, are the main factors affecting plant growth when drilling wastes are buried or contained in deep trenches. Plant growth may be depressed by impeded root growth and development and oxygen deficiency in the rooting zone caused by compaction of surficial material during reclamation. This effect is stronger in clayey soils than in sandy soils.

Soil chemical properties also affect plant growth. Salinity increases which result in EC above 2 mS/cm for trees (Edwards, 1985) and above 4 mS/cm for many other plants, depending on their salt tolerance, will cause yield reductions. Sodicity impedes plant growth by creating a poor soil structure or through phytotoxic effects. Salinity and sodicity effects will be enhanced and persistent if the clay content and/or background salinity/sodicity of the soil is high and the climate is dry. On sandy soils, salts may be leached out and therefore not affect vegetation but may contaminate groundwater.

Investigation of the effect of various elements on plant growth indicates that there are deficiency levels, optimum levels, and toxicity levels and these levels vary with the type of plant, type of soil, and climate. In general, the major nutrients required by plants, which may also occur in drilling muds, are N, P, K, S, Ca and Mg; trace elements are Fe, Mn, Zn, Cu, Cl, B and Mo. Other elements such as Na, Al, and Si can stimulate the growth of certain plant species (Finck, 1976). Elements of special environmental concern are those, such as cadmium and selenium, which are non-toxic to plants at levels which are harmful to animals and humans (Environment Canada, 1984).

Effects on Surface Waters

Considering that direct surface water disposal is not allowed surface water contamination related to drilling activity could only occur as the result of:

Accidental release through sump or lease berm disruption.
Improper off-site drilling fluid disposal.
Leaching from on or off-site disposal areas. This applies to fluids and solids.
Secondarily through surface water discharge of contaminated groundwaters.

To minimize any potential risk to the environment the ERCB has required that fluids for off-site disposal pass a Trout Toxicity Test (one of two trout fingerlings (3-10 cm) must survive 96 hours in treated fluids). Considering the complexity and diversity in drilling fluid components an overall aquatic toxicity evaluation has been considered to be an effective regulatory control that can be easily implemented. Proposed amendments to the fluid disposal guidelines will allow use of Microtox (bacterial luminescence) as an alternative toxicity method. It is a more rapid test and the correlation between the two methods is high

(Strosher, 1984). These tests, however, do not identify specific constituents which may be harmful in terrestrial systems. Much additional testing is needed to evaluate specific detrimental characteristics, loading rates, or methods of surface disposal and burial.

Effects on Groundwaters

Constituents that are transported by groundwater flow from a drilling waste disposal site can be classified as either dissolved (solutes), suspended solids (colloids), or oils (immiscible liquids).

From a groundwater point of view, the drilling waste disposal methods can be divided into two basic types. The surface spreading and squeezing methods involve waste disposal over a relatively large area whereas the burial and trenching methods involve disposal in a relatively small space. Contaminants reach the groundwater as either filtrates or leachates. In the case of surface disposal any contamination is partially mitigated by microbiological processes in the upper soil zone.

When disposing of drilling waste, it is necessary to consider the entire watershed because contaminants migrating in groundwater may be in transit for long periods of time and may travel large distances. Also, it is very difficult and expensive to renovate polluted groundwater. Therefore, every attempt should be made to mitigate both the pollutant migration and the contamination in the disposed waste itself before disposal.

ASSESSMENT OF GUIDELINES

Currently, there are five documents with appendices regulating and guiding drilling waste disposal. They are listed below, followed by Consultants' recommendations for their improvement.

1. ERCB Interim Directive ID-OG75-2 "Sump Fluid Disposal Requirements"
2. ERCB Interim Directive ID 81-1 "Subsurface Disposal of Drilling Fluids"
3. "Guidelines for Sump Fluid Disposal on Crown Land - White and Yellow Areas" - 0799G for Public Lands Division Staff.
4. ENR Information Letter 82-5 "Potassium-based Drilling Mud Systems".
5. Oil and Gas Regulations, R-57 (Rev. 33:2/81) "Care of Well Sites and Battery Sites".

Major improvements recommended:

- more notification and surveillance time.
- should attempt to make decision-making process more objective: currently much is based on subjective assessment of the field officer.
- volume (6,000 barrels) is not an adequate criteria for testing: all sizes of sumps should be tested.
- more objective assessments of potential for surface and groundwater contamination are needed.

- sampling, laboratory, reporting, and interpretation procedures should be standardized to allow good record keeping and make the surveillance better.

- permissible spread rates and total loadings for various constituents under various environmental conditions should be established.

- should address the solids as well as the fluids components of drilling wastes.

- all sumps should be tested by the drilling/mud industry: surveillance would entail testing a percentage of the sumps as is done now.

In the Consultant's opinion, the proposed guidelines being prepared address many of the concerns which the above recommendations focus on.

RESEARCH AND ACTION

There are significant gains to be achieved quickly in environmentally safe disposal of wastes through organizational or structural changes to existing procedures. In the longer term (5 years or more) considerable research is needed to provide technical understanding/solutions to current information gaps. The recommendations are summarized in point form.

Organizational Improvements

- Develop regional waste management plans.
- Design practical, rapid, cost-effective, site-specific waste management plans.
- Develop rapid testing procedures for the routine types of analyses. For example, field or mobile labs to do quick testing of key constituents. Prior knowledge of what products and their chemistry the driller intends to use would be helpful in selecting required analyses.
- Drilling and mud industries must give high priority to environmental impact of wastes.
- Guidelines, directives, data management systems, and penalties/rewards must be revised or established in line with the foregoing.

Technical Needs

- Research is urgently needed to gain a better understanding of characteristics, handling, decomposition, and impacts on the environment of organics, trace elements and heavy metals. Consider impact of sub-lethal levels of toxic substances.

- Sampling, analysis and interpretation techniques through to calibration with field observation need further research and standardization.

- Adopt existing technology in computer modelling of waste leachate behavior in disposal environments.

- Permissible loadings for various waste constituents on soils should be established. Mitigation measures must be developed where appropriate.

- Technologies for reducing waste volumes and concentrations require further development.

- Research on characteristics, handling and safe disposal of solids is needed.

- Interactions of different muds should be studied in terms of treatment and disposal. Compounds that should not be mixed should be flagged.

- Examine long term impact of drilling wastes by investigation of old sites.

- Develop standardized monitoring procedures for disposal areas.

FIELD MANUAL

A manual has been prepared to assist field officers in monitoring environmental aspects of waste disposal. It focusses on the following items which are covered in detail in the Field Manual as well as in the main report.

- Site suitability for sumps and surface disposal: soils, materials, vegetation, land use, topography, etc.
- Waste characteristics: volume, concentration, toxicity, etc.
- Permissible loadings: maximum concentration of waste constituents for disposal, maximum concentrations on a per hectare basis, for salts, specific ions, and metals.
- Alternatives to surface disposal: alternative mud systems, "safe" burial, treatment, solidification and waste utilization.

CONCLUSION

The oil and gas industry and regulatory government agencies must pay greater attention to the environmental impacts of drilling wastes, because:

- large volumes of wastes (approximately 5 million m^3 in 1985) are disposed annually,
- many sumps contain noxious fluids (60% of some 600 sumps tested in 1983-84 were found to be toxic) and solids which are probably noxious too but have not been tested routinely to date,
- many sumps have large amounts of salts, extreme pH levels, and excessive concentrations of specific ions, for example, sodium, chloride, sulphate, trace elements and heavy metals, and
- organic compounds which are extremely variable in composition and toxicity may be present in sumps.

This literature review and accompanying field manual attempt to identify practical methods for environmentally acceptable disposition of wastes based on what is "known". In fact, there are many "unknowns" and it will take much effort and adequate funding to provide workable alternatives that will minimixe potential for serious environmental pollution and human health hazards.

The following broad areas need urgent attention:

- drilling and mud treatment industries need to direct more attention to environmental consequences of the additives they use and the products they ultimately release, to avoid or neutralize harmful compounds;

- operating and regulatory agencies need better data management, for example, on mud systems, sump constituents, lab analyses, waste disposal techniques, waste management plants, and monitoring programs; and

- environmental research is needed to determine permissible waste loadings, to streamline and standardize sampling procedures through to interpretations, and to convert "wastes" into "useful" products.

Carefully planned, integrated and "systems" approaches considering initial composition of mud additives, drilling requirements, waste handling, waste treatment, waste disposal/recycling and waste processing for utilization in addition to drilling performance, cost and convenience should allow cost effective, environmentally safe drilling procedures to be developed.

1. INTRODUCTION

Specific objectives of the project were as follows:

- To identify physical and chemical problems associated with drilling waste disposal based on a literature review and consultation with various agencies.

- To assess criteria contained in existing Alberta guidelines.

- To develop, test, and demonstrate field application of a decision-making flowchart.

- To identify research gaps and indicate mitigation measures for drilling waste disposal based on new technologies and options for waste utilization.

2. BACKGROUND

Over 100,000 wells have been drilled in Alberta since oil and gas production began (Lloyd 1985). Major oil and gas fields in Alberta are shown in Figure 2.1. In 1985, 8,476 oil and gas wells were drilled in Alberta totalling 9.3 million metres drilled (ERCB 1986). Considering that approximately 0.5 m^3 of drilling fluids result from every metre of drilling this amounts to nearly 5 million m^3 or 30 million barrels of waste drilling fluids which had to be disposed in 1985.

Drilling wastes can be toxic to plants and animals (Strosher et al. 1980; Shaw 1975); and thus to humans if transferred through the food chain. Concern has been expressed that current disposal practices may lead to contamination of soil, groundwater and surface water.

The nature of drilling wastes and of the environment for drilling waste disposal are addressed in Sections 3 and 4, respectively. Problems associated with drilling waste disposal as documented in the literature are compiled in Section 5.

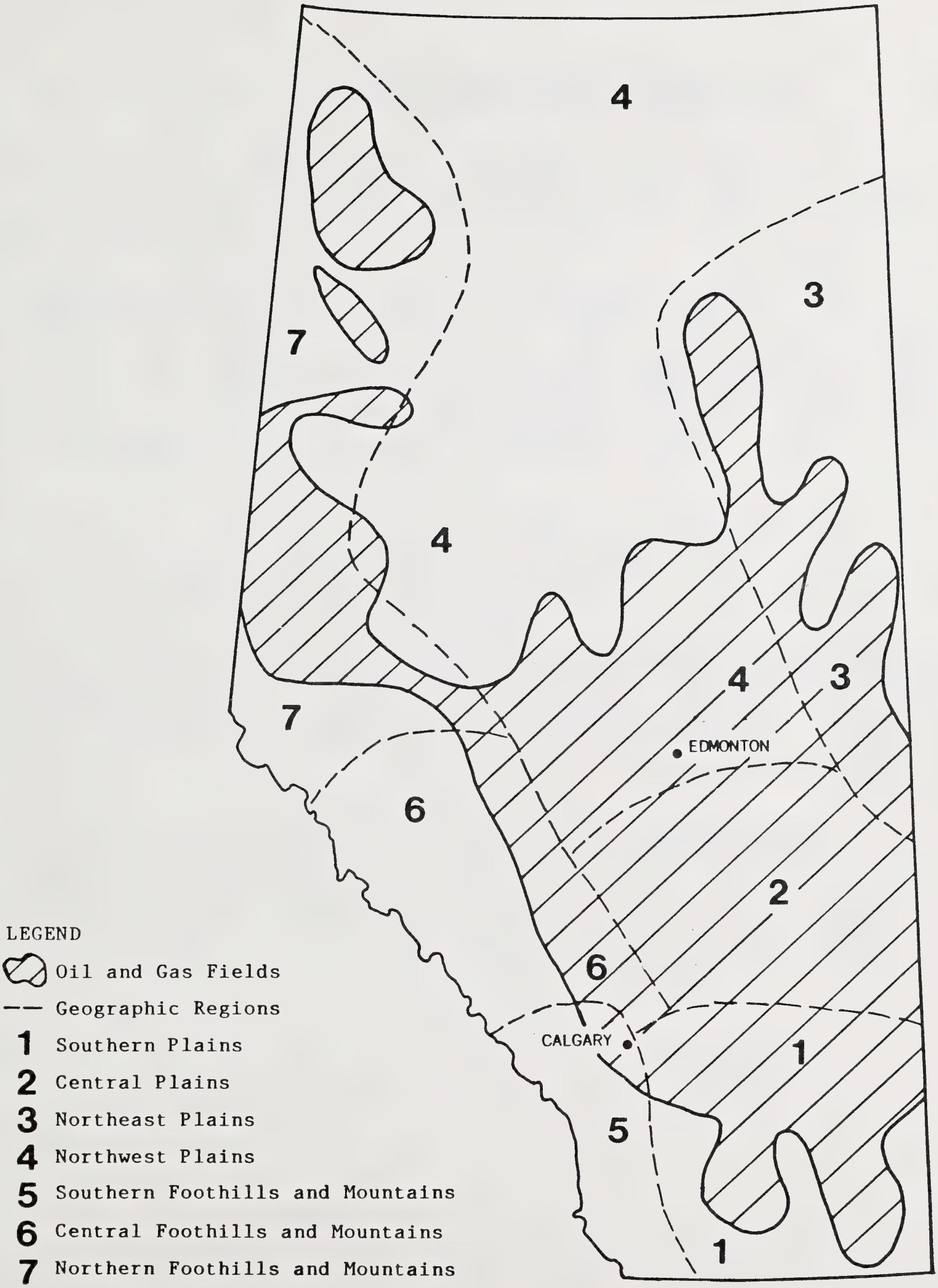


Figure 2.1 Major Oil and Gas Fields in Alberta (after ERCB, 1984).

3. CHARACTERISTICS OF DRILLING WASTES

Drilling wastes comprise drilling fluid (or mud); drilled cuttings (shales, salts, anhydrite); formation fluids (brines, crude oil); completion chemicals (acids); and others which may inadvertantly enter the sump including rig washes, waste lubricants, coolants, and domestic waste (Shaw, 1975). Drilling mud is a major contributor to the chemical and physical properties, as well as toxicity of the sump contents (ERCB, 1985; Specken, 1985). A section on major drilling mud systems used in Alberta therefore precedes the characterization of sump contents.

Drilling fluid selection is governed by expected and actual conditions encountered during drilling (such as formation pressures and temperatures, presence of salt formations, formation permeability and stability) as well as economics which implies successful completion of drilling in the shortest time possible. A third factor is preference of the supplier and operator.

Environmental safety of the fluids has not been a prime consideration to date but it should become a selection factor as regulations regarding disposal become tighter and monetary value is attached to various disposal options.

3.1 MAJOR DRILLING MUD SYSTEMS IN ALBERTA

The major drilling mud systems and mud types presently used in Alberta are:

Mud Systems	Mud Types
Fresh Water:	Native Mud, Clear Water Drilling Fluid, Inhibitive Water Drilling Fluid, Bentonite Viscosified Mud, Extended Bentonite Mud, Bentonite-Water Viscosifying Polymer Mud.
Saline Water:	Inhibitive Mud, Saturated Mud.
Invert:	Invert Emulsion Mud (water is dispersed in oil up to 50% by volume) (Ziedler, 1986, personal communication).

A detailed description of major components, applications, and regional distribution of the main systems, as well as major additives are given in Appendix Tables A1 to A4.

Fresh water muds (Appendix Table A1) are the cheapest and most frequently used systems and constitute the vast majority (about 95%) amongst all the wells drilled (Ziedler, 1986; personal communication). They are used whenever no major problems such as excessive temperatures, pressures, and salinity or water sensitive formations are encountered. A common make-up is water, bentonite ("gel") as viscosifier, carboxymethyl cellulose for fluid loss control, lignosulfonates as thinners (Appendix Table A4) and often polymers for increased yield. The pH is between 9 and 10.

The remaining wells are drilled mainly with KCl-polymer muds and Invert muds. Both systems are used in the Foothills region; KCl systems are used in the heavy oil recovery areas (NE Alberta, e.g. BP) and occasionally in the Plains region (Shell, 1984).

KCl muds (Appendix Table A2) have extremely high salt content (20,000-40,000 ppm) in a water/bentonite/polymer medium. The pH is between 9.5 and 10.5. Corrosivity due to high salt concentration necessitates the addition of oxygen scavengers.

Invert muds (Appendix Table A3) consist of water dispersed in diesel oil with the help of emulsifying agents; of weighting material (barite) for pressure control; of organophilic clay as viscosifier and calcium chloride in concentrations of about 300,000 ppm. Invert muds are the most expensive mud systems and are usually completely recovered apart from coatings of the mud on the drilled solids.

Saturated salt water muds (Appendix Table A2) constitute a minor portion of the drilling fluids (Ziedler, 1986; personal communication) and they are used mainly in areas of the Prairie Evaporites (Appendix Figure A1). They are characterized by extremely high salt concentration (near saturation point) in a near neutral medium of water, prehydrated bentonite or attapulgite or polymer or polyanionic cellulose. If starch is used for fluid loss control a bactericide (paraformaldelyde) is usually added.

Drilling fluids described will enter a sump pit in various amounts. Some components might reach the sump unaltered, other components, especially organic constituents, might undergo changes depending on temperature and pressure conditions and presence of contaminants when circulating through the borehole. The prediction of what the sump contents may be for various systems is complicated by the addition of materials other than drilling fluids, as mentioned earlier. Geological materials entering the sump as cuttings are, in a very general sense, sands and shales in the Plains area south of a line from Rocky Mountain House - Leduc - Provost; and salts such as halite (NaCl) where drilling is through evaporites. North of this line, and in the foothills and mountains, carbonates ($CaCO_3$) are encountered in addition to sands, shales and possibly salt.

3.2 CHARACTERISTICS OF SUMP CONTENTS

Sumps contain a complex mixture of liquids and solids, organic and inorganic compounds. Some of the components may be inert or interact synergistically or antagonistically. Simply breaking down drilling fluids into their components and investigating their individual effects on terrestrial or aquatic life therefore does not necessarily reflect the effects of whole sump contents which may be quite different (Shaw, 1986, personal communication; Nesbitt and Sanders, 1981). In the following sections, physical and chemical characteristics, and noxious properties of sumps are described.

3.2.1 Physical Characteristics

Sump contents generally consist of three distinct phases:

- a thin layer of oil scum on the surface,
- a thick fluid phase with dissolved components (e.g. salts, organics) and suspended solids (e.g. clays),
- a bottom layer of sludge containing most of the solids which have settled (Specken, 1985).

Specken (1975) reports that sumps tend to become stratified with time. The amount of suspended solids often increases with depth, especially if overall concentrations are high. Associated chemical features are high concentrations of ions (dissolved solids or salts) and high pH. Further, the concentration of dissolved noxious organics is suspected to behave similarly to the salts (Specken, 1975).

Horizontal variability between different points in the sump occurs due to release of the waste from mainly one point.

The volume of the sump contents is largely dependent on the depth drilled. Approximately 0.5 m^3 of waste drilling fluids results from every metre of drilling. By the end of a drilling operation, an appreciable volume (typically 5,000 to 50,000 barrels, and occasionally as much as 100,000 barrels) of waste fluids have accumulated in the sump (Specken, 1975). Volume and concentration of the fluids may change over time due to precipitation, evaporation, lateral and downward movement into soil and possibly groundwater, or overflow of the sump (Abouguendia, 1985).

3.2.2 Chemical Characteristics

The following chemical parameters which might affect the environment have been identified: salinity (total dissolved solids), sodicity, specific ion content, pH, suspended solids, trace elements and organic compounds. The first four parameters are routinely determined if samples are analyzed for surveillance purposes. The toxicity (see Section 3.2.3) of the whole fluid which might be due to any of the above parameters or their interaction is also tested.

Salts may adversely affect soils, vegetation, surface water or groundwater. Additions of trace elements may be beneficial to plants, animals and humans in low concentrations, but may become noxious in high concentrations. Effects of organic compounds, which vary greatly in composition and toxicity, are the most complex and least understood. Organics vary greatly in composition and noxious properties.

Efforts to keep sump volumes below 6000 barrels can lead to increased concentration of the above constituents. The consequence could be contamination of soils, vegetation, groundwater or surface water when the sump contents are disposed. Sump chemistry can become more complicated when central sumps are used. These sumps accept drilling wastes from several wells which increases the sump volume; it may also lead to a complex sump chemistry which could make treatment difficult.

3.2.3 Toxicity

According to ERCB records a total of 10,929 wells were spudded in 1983-84; 574 sump fluids of these wells were tested and 344 or 60% of these were found to be toxic (ERCB, 1985). Toxicity of sump fluids is currently assessed by a 96 Hour Trout Test or by a Microtox Test which uses bacterial fluorescence to indicate well-being of the test population. Both are standard tests used in ecotoxicology to assess toxicity and lethal potential of complex mixtures. Both tests yield the same results about 75-80% of the time (Shaw, 1985).

A major concern is that toxicity to trout does not serve as a meaningful proxy for the impact of drilling wastes on soils and groundwater. This becomes self-explanatory in the next paragraph. Therefore, a more comprehensive analysis of sumps is needed in order to make meaningful predictions regarding impact on the environment.

Nevertheless, the toxicity of a sump, as measured by the Trout or Microtox tests, is related to the physical and chemical factors outlined previously. Suspended solids such as bentonite or other clay particles coat the gills of a trout which dies from suffocation. The toxicity of specific ions to fish seems to depend on the balance between monovalent and divalent ions. Shaw (1985) found that concentrations of sodium and potassium salts ($-HCO_3$, $-Cl$, $-SO_4$, $-NO_3$, $-OAc$) were toxic at concentrations as low as 20 ppm and 15 ppm, respectively; but fish were still alive at concentrations of 20,000 ppm and 15,000 ppm of calcium and magnesium salts, respectively. The divalent cations protect the cell-wall barrier against monovalent ions. Ammonium phosphate and sulphate which are used in drilling muds to inhibit clay swelling have been found to be toxic at low concentrations. This may be due to the release of ammonia which is dangerous to animal life at concentrations <100 mg/1 (Shaw, 1975). Toxicity of organics is the area least understood. Some general findings by Shaw (1975) are:

- Some hydrocarbons such as crude oil produced from formation tests may not be lethal until the concentration is over 400 mg/1;

- Some detergents such as rig-wash compounds are not lethal until the concentration is over 200 mg/1;

- Many of the oil and detergent combinations that separately are lethal at fairly high concentrations are extremely lethal as mixtures when quite diluted;

- Diesel fuel from fuel spills and machine cleanup, depending upon the method of manufacture, may be very toxic;

- The clear water extracted from a diatomaceous earth slurry as used in drilling muds is not toxic even when the slurry used 5 lbs/bbl (14,285 mg/1);

- Many of the polyacrylamide bentonite flocculants or extenders used in drilling fluids are not toxic at low concentrations (below 100 mg/1). This is well within the effective range;

- Corrosion inhibitors from drilling muds or packer tests are generally very toxic (in the same toxicity class as bacteriostats, which they resemble in structure);

- Some humic acid mud thinners are toxic at very low levels;

- Carboxymethylcellulose used in drilling muds as a viscosifier or water loss additive generally is not toxic unless used beyond the normal concentration (possibly because food grades are marketed for use in drilling fluids);

- Tannin-type mud thinners tend to be less toxic than other thinners (provided that they are tannins and not mixtures containing other materials);

- Food-grade glycols and some of their polymers, which could be used in special muds or as motor antifreeze, may be only very slightly toxic. Some closely related compounds are quite toxic;

- Some lignosulphonate mud thinners are toxic at concentrations exceeding 100 mg/1; and

- Some of the phosphoric acid ester dispersants, which could be used in drilling fluids or for rig-wash compounds, are toxic above the 10 mg/1 level.

Data from ERCB (1985) suggest that sump fluid toxicity is not related to well depth.

3.2.4 Examples of Sump Fluid Chemistry and Toxicity

Information on sump fluid chemistry and toxicity is currently not easily accessible and has barely been quantified. Handwritten records on every sample analyzed are kept at the E.R.C.B. Research Lab in Calgary and were compiled for this project for the last 6 months in 1985. The results are given in Appendix Table A5. Sampling procedures to be used are those outlined in the E.R.C.B. Guidelines (Interim Directive ID-OG75-2; Appendix A and B). Sampling depth, estimated sump volume and a visual and sensual assessment of the sample were given sporadically on the records. Information on the mud system used is hardly ever available on these records, but has been requested to be noted on the "tower sheets" for every well drilled. These are kept separate in a different E.R.C.B. division. Appendix Table A5 provides region/location, probable mud system used (inferred from the chemistry with the help of the E.R.C.B. Chief Chemist); a note whether the sump had been treated or not, and visual description of the sample; estimated volume if available, as well as toxicity and chemical parameters determined.

Most of the samples analyzed were derived from Fresh Water Mud Systems, several Salt Water Mud Systems and one Invert Mud (which was specified on the record).

Salt contents are highest in sumps from the salt systems, even though concentrations have been diluted from what would be originally expected. The reaction (pH) in all sumps is neutral to alkaline, but occasionally acidic which might be due to rig washes or completion fluids (Shaw, 1986; personal communication). In muddy samples, the concentration of total dissolved solids determined (TDS det.) is much higher than of the total dissolved solids calculated (TDS calc.). Volumes are seldom known but from the few volumes specified it must be inferred that sumps with low volumes can also be toxic. Sumps with high salt concentrations may be non-toxic for fish even if concentration of divalent cations is low, whereas sumps with low salt concentrations may be highly toxic. This suggests the possible presence of toxic organic constituents.

Three sumps derived from three different drilling systems were analyzed specifically for this project by a commercial lab. The drilling systems are KCl-Polymer, Fresh Water Gel and NaCl. Grab samples were taken from various depths from each system and integrated into three composite samples (each composite sample representing a system). Samples were collected from 10 locations in the Fresh Water Sump, but only from one location in each of the other sumps because of a thick surface ice layer. Samples from the KCl and NaCl sumps may therefore not necessarily be representative, and analytical results have to be interpreted with caution.

The solids and fluids portions of each composite sample from each sump was analyzed by a commercial lab for specific ion content, EC, SAR, pH, available N, P and K, content of oil and organic carbon, exchangeable sodium percentage (ESP) and gypsum. Results are presented in Appendix Table A6.

Further, a simultaneous multielement analysis of the solids portion of these samples was conducted by optical emission spectrometry using an I.C.P. (Inductively Coupled Plasma) Spectrometer. Total elements were determined on a complete acid digest of the samples with 12 N nitric acid and 70% perchloric acid, and on an EPA leachate (leachate according to Environmental Protection Agency) for which the sample was diluted with water (1:20) and its pH adjusted to 5 for 24 hours. The filtrate was analyzed and is considered to represent leachates which might occur under field conditions. Total metals were also analyzed in the fluids. Results are summarized in Appendix Table A7.

Toxicity was determined by the 96 Hour Trout Test on filtrates of the samples (liquids portion) and on 24 hour leachates (solids portion) with distilled water (Appendix Table A8).

The fluid phase of each of the same three composite samples was analyzed at the ERCB Laboratory using the same procedures applied when samples are submitted by field personnel for surveillance purposes. The results for chemical parameters are included in Appendix Table A6. Toxicity test results are provided in Appendix Table A8 for the trout test and in Appendix Table A9 for the microtox test.

A direct comparison between the results of the two laboratories is not possible because one lab analyzed the solids portion while the other analyzed the fluids. Nevertheless, both analyses exhibit similar trends. The NaCl sump has the highest concentration of salts with sodium and chloride being the prevalent ions. Salinity of the KCl sump is somewhat higher than that of the Fresh Water Gel Sump but both of these sumps have lower salinity levels than the NaCl sump. Surprisingly, dominant ions in the KCl sump are sodium, calcium, chloride and sulphate while the potassium concentration is low. In the Fresh Water Gel sump there is no pronounced dominance of ions but the concentration of sodium is slightly higher relative to other ions. All three sumps are alkaline with pH values around 10. Analyses of both fluids and solids portions exhibit similar trends.

Results from the multielement analysis of the EPA leachate show elevated levels of most elements in the NaCl sump relative to the KCl and the Fresh Water Gel sumps. Only cadmium, cobalt and magnesium levels are somewhat lower than in the KCl sump. Analyses of the fluids samples indicates that barium, boron, chromium, copper, iron and zinc tends to be above acceptable levels in all sumps according to the Alberta Surface Water Quality Objectives.

Both microtox and trout bioassays indicate high toxicity of the NaCl sump and the Fresh Water Gel sump, but only minimal toxicity of the KCl sump. The leachate of the solids portion is more toxic than the filtrate of the fluids portion. Dilution of the NaCl sump would greatly reduce toxicity levels.

3.3 CURRENT DISPOSAL METHODS ON PUBLIC LANDS IN ALBERTA

The disposal on Public Lands is regulated by ERCB Guidelines (Interim Directive ID-OG75-2) which are currently under review. At present sump fluids under 6,000 barrels in volume may be disposed on lease, regardless of their chemical compositions or toxicity, given the lease is at least 300 feet from the normal high water mark of a water body. Volumes over 6,000 barrels are disposed off-lease and have to meet, or if necessary be treated to meet, the following criteria:

Chloride Content	<1,000 mg/l
Sulfate Content	<2,000 mg/l
Total Dissolved Solids	<4,000 mg/l
pH	5.5 - 8.5
Trout Survival Test	1 of 2 Trout Fingerlings must survive 96 hrs.

Disposal to a subsurface formation is acceptable if that formation is not locally productive of oil and gas, and if the formation water in the disposal zone has a total dissolved solids content greater than 20,000 mg/l. If KCl drilling fluids are used a disposal plan is required which has to be approved prior to lease construction.

The current guidelines only address the fluids part of the drilling wastes, the solids part is regulated but not address. Five basic disposal methods are used at present:

1. In pit burial;
2. Trenching;
3. Standard squeezing;
4. Surface spreading; and
5. Deep well injection (Lloyd, 1985).

Disposal by well injection is not directly relevant to this project and will not be addressed.

Pit burial means the capping-off of the sump pit. The pit has to be impermeable. The area of the sump pit usually settles requiring refilling of the settled area. (Canadian Petroleum Association, 1984).

Trenching involves the digging of deep slots into the lease with a backhoe, then allowing the slots to fill partially with sump fluid. Soil is pushed back into the trench in such a way that the fluid is absorbed into the soil rather than being capped. Trenches may intersect permeable sandy or gravelly lenses/formations and such conditions may lead to groundwater contamination.

Squeezing refers to the process whereby a bulldozer slowly pushes fluids out of one end of the pit by pushing in fill material at the other end. This procedure is still accepted in Alberta (Lloyd, 1985), even though a portion of the solids remains in the pit. The fluids are mixed with the soil on the lease area (usually B horizon material) and later are covered with topsoil.

Pit burial and trenching have been commonly practiced in the forested areas (Green Zone) because tree clearing is minimized in order to maintain the timber base, and topography, proximity of water bodies and suitability of soils restrict the working space. Trenching and squeezing have been commonly used on open rangeland (White Zone). Burial and trenching are now discouraged because of lower degradative potential, possible formation of anaerobic decomposition products which are uncontrollable, and potential contamination of groundwater with salts or organics (Lloyd, 1985).

Land spreading refers to the application of sludges or liquid wastes to soils by surface spraying or spreading, or injection below the surface (Glen and Orchand, 1986). This treatment utilizes the natural biological, chemical and physical processes in the soil which acts as a treatment medium. It is a method commonly used in municipal sludges and it is not the preferred drilling waste disposal option.

4. ENVIRONMENTS FOR DRILLING WASTE DISPOSAL IN ALBERTA

4.1 SOILS

The soils of Alberta vary greatly, regionally and locally, in their physical, chemical and biological characteristics. Current land use policies require that soils disturbed by drilling activities be reclaimed to their original level of productivity or better. Reclamation success depends largely on the sensitivity of soils to disturbance. Factors which determine soil sensitivity during and following disposal of drilling waste include, parent material, the physical and chemical properties of the soil, vegetation, climate, topography (landform) and and present land use. Table 4.1 provides a generalized breakdown of these parameters along gradients representing low to high environmentally sensitivity/high to low tolerance for surface waste disposal. Note that each parameter must be examined separately because this Table was not intended to provide a systems approach. By rating each parameter one can examine various combinations of conditions to find the most tolerant situations. At the same time various mitigation measures can be considered for each limitation. This ultimately enables one to plan appropriate management practices that will minimize harmful environmental effects. Appendix B1 provides a detailed description of the above factors. The main points are summarized in Table 4.2.

4.2 SURFACE WATERS

Background levels of surface water environments have to be known before the effects of drilling waste disposal can be assessed. Representative water quality data for lakes and rivers in Alberta are presented in Appendix Table B3.

With some exceptions salinity levels of surface water bodies in Alberta are low (EC <2 mS/cm) and dominated by calcium bicarbonate.

Table 4.1 Sensitivity/Tolerance of Environmental Parameters to Surface Waste Disposal.

◄---------------------- SENSITIVITY TO/TOLERANCE FOR SURFACE WASTE DISPOSAL ----------------------►

Low Sensitivity/ High Tolerance			High Sensitivity/ Low Tolerance
PARENT MATERIALS			
Fluvial-Lacustrine Till (Plains) Lacustro-till	Fluvial Lacustrine Bedrock (plains)	Fluvial-Eolian Till (Foothills and Mountains) Bedrock (Foothills and Mountains)	Eolian Organic
SOILS			
Black Chernozemic Dark Gray Chernozemic and Dark Gray Luvisolic	Dark Brown Chernozemic Gray Luvisolic	Brown Chernozemic Brunisolic	Solonetzic Gleysolic Regosolic (floodplains) Organic
VEGETATION			
High salt tolerance Vegetation not for human consumption or entering the food chain	Medium salt tolerance Vegetation entering food chain	Low salt tolerance	Low salt tolerance Vegetation for immediate human consumption
CLIMATE			
Warm, moist (Black Soil Zone) (Dark Gray Soil Zone)	(Dark Brown Soil Zone) (Gray Soil Zone)	(Brown Soil Zone)	Droughty, windy, cold (SE Alberta, high elevations) (Undifferentiated Mountain Complex)
TOPOGRAPHY/LANDFORM			
Level to gently sloping uplands	Moderate slopes	Steep slopes	Very steep slopes Floodplains Dunes
LAND USE/POPULATION DENSITY			
Wildlands Rangelands Sparse population	Low productivity forests and agriculture	High productivity forests and agriculture	Crops for human consumption Dense population

Table 4.2 Key Environmental Factors in Assessing Tolerance to Waste Disposal.

Key Factors	Features	Applications/Considerations
1. Parent Materials	- texture, depths and continuity of layers, permeability, fracturing, stoniness	- effects of disturbances - effects of waste application - soil capability for agriculture, forestry, other uses
2. Soils	- emphasis on topsoil (A horizons) and subsoils (B horizons) - soil properties: organic matter content, pH, texture, structure, consistence, salinity, SAR, cation exchange capacity, fertility - site characteristics: moisture regime, drainage class, temperature regime, slope position and aspect	- disposal methods: areas and depth of impact - potential hazards: runoff, erosion, compaction, leaching through to groundwater - biodegradation: rates, amendments needed, other management practices required - tolerable limits for added constituents, direct and indirect effects - productivity and capability for various land uses - timing of activities: season, moisture conditions
3. Vegetation	- type: annual crops, forages/ pasture, shrubs, trees - salt tolerance - rooting depths preferred - sustainability and succession	- direct or indirect entry to food chain - cover for erosion protection - productivity and economic value - self-sustaining cover/succession - aesthetic concerns/indicators of problems
4. Climate	- season - moisture regime: regional pattern, site/time specific - temperature regime: growing season, heat units - winds	- timing of disposal and reclamation activities - rates of biodegradation, leaching critical periods - adapted plant species for re-vegetation
5. Topography/ Landform	- steepness, lengths and aspects of slopes - "active" landforms: dunes, floodplains, slumping/sliding areas - occurrence and types of wetlands - configuration of watersheds	- levelling requirements for drilling/disposal operations - location of access roads - erosion, runoff hazards - depth to and extent of aquifers - groundwater regime: recharge and discharge areas
6. Land Use/ Population Density	- agricultural crops: cereals, oil seeds, forages (harvest, seed production, not grazing) - horticultural crops: root crops, vegetables, fruits - pasture crops: beef, dairy, other - trees: commercial vs non-commercial - population density/type of use: building, dwellings, recreation, roads - water supply: wells, surface ponds, streams, etc.	- health hazards to man and animals via food chain transfer, exposure or contamination of water supplies

Saline sloughs and small lakes occur in the south-central portion of the province, e.g. Blood Indian Reservoir. Total dissolved solids content tends to increase as one moves away from the foothills. Sodium and sulphate inputs are often the major cause of this increase.

Lakes and rivers in Alberta are alkaline and pH levels range from approximately 7.0 to 8.5. Minimum values occur under ice in the winter; maximum levels are recorded in late summer or fall.

Heavy metals in all systems are usually near the limit of analytical detection. This is a function of high pH which favours precipitation of the heavy metals and their adsorption to particulates.

Levels of organic carbon, nitrogen and phosphorus vary and tend to be higher in the prairie and parkland relative to the foothill and mountain drainage systems. During the open water season ammonia levels are low due to nitrification and uptake by aquatic plants and algae. The exceptions are sites immediately adjacent to point source municipal effluents. Under ice, levels of ammonia are often elevated due to decay of organic material and reduced rates of nitrification and uptake by plants.

Despite these general patterns water quality can vary markedly over small distances. For example, Moore and Cold Lakes are located in close proximity to each other; yet their quality characteristics are quite different. This reflects their relative size and different watershed/runoff characteristics.

4.3 GROUNDWATERS

There is a wide range in both the quantity and quality of groundwater available in Alberta, resulting from the complex interplay of topography, geology and precipitation. Groundwater is recharged in topographically high areas through the infiltration of precipitation and surface water; it will then flow through aquifers and be discharged in topographically low areas (Figure 4.1). The amount of recharge is dependent on many factors including precipitation, evapotranspiration, surface runoff and infiltration rates.

In general, the groundwater surface (water table) is a subdued replica of the topography. Local groundwater flow is relatively shallow and interactive with nearby topographic features such as rivers, marshes and hills: regional groundwater flow is relatively deep and unaffected by local topography.

Important groundwater features to be considered for drilling waste disposal are the direction of the flow, the depth of the water table, the depth to nearby aquifers, and the proximity of existing or potential water supply sources (e.g. wells, springs, dugouts and sloughs). An explanation of groundwater flow theory and important features related to waste disposal is given in Appendix B3.

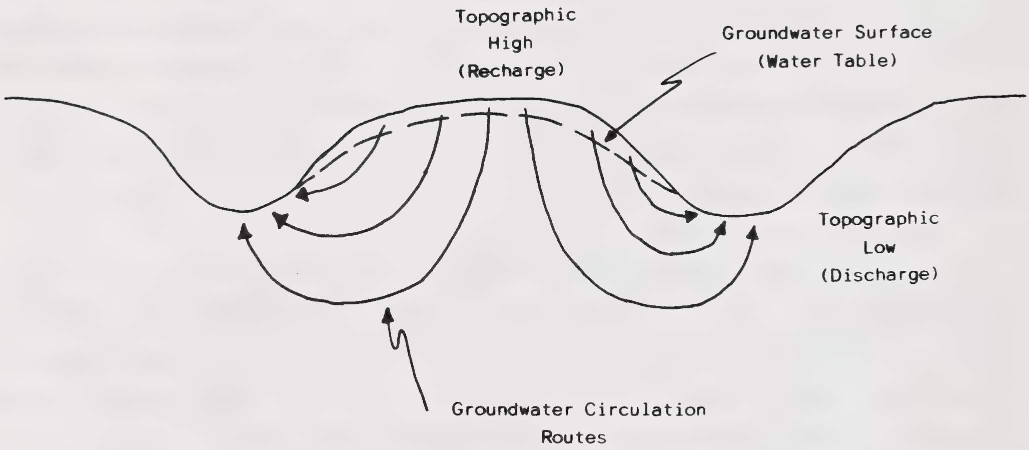


Figure 4.1 Generalized Groundwater Circulation.

4.3.1 Bedrock Environments

The predominant hydrogeological region is the Interior Plains. It consists of flat to gently dipping sedimentary strata that increase in thickness towards the west. Bedrock aquifers within this region are typically sandstone and coal, which have been fractured. Water quality of these aquifers is poor. The lateral extent of aquifers in this region is variable due to their fractured nature, which is structurally controlled.

Strata in the Cordilleran Region (mountains and foothills) are steeply dipping and are mainly sedimentary. Bedrock aquifers in this area are commonly sandstone or limestone. Water quality in the deeper aquifers is usually poor and not suitable for human consumption.

Bedrock strata in the northeast corner of the province are varied in composition and age. Devonian and Cretaceous aquifers in this area are flat dipping and comparatively uniform in thickness. With the exception of the subcrop or outcrop areas, groundwater contained in these deposits has high mineralization and is not suitable for human consumption.

4.3.2 Surficial Environments

Surficial deposits in Alberta are largely related to glacial activity. Till deposits up to 100 m thick are of limited hydrogeological importance even though they may include thin, discontinuous layers of higher hydraulic conductivity sand and gravel.

The lacustrine deposits are usually homogeneous and consist of very low hydraulic conductivity silt and clay in the order of 10-20 m thick. Such deposits can be considered as aquitards that will not transmit water.

Throughout the province, and particularly in the northeast, glacial outwash deposits of sand and gravel are present. Such materials are water-sorted by glacial meltwater and surface water, and therefore potentially good aquifers. These deposits, although typically of variable extent and thickness, are a major source of domestic water.

A very important surficial aquifer, which is not directly related to glacial activity, is the buried valley aquifer. Such aquifers contain high hydraulic conductivity sand and gravel deposits (usually less than 100 m below ground surface). They are the highest yielding aquifers found in the province and are an important supply of domestic water. Post-glacial rivers and streams tend to parallel the course of pre-glacial valleys in the foothills where such valleys are more deeply incised. However, in the comparatively flat prairie regions, present day river and stream courses frequently have no relationship to the pre-glacial valleys.

4.3.3 Hydrochemistry

The hydrochemistry of groundwater is primarily dependent on its age and the type of deposits through which the water flows. Certain groundwater types can often be associated with particular geologic deposits through which the water has moved, such as till or shale. In general, the longer the water has been circulating below ground surface, the greater the mineralization.

As water enters at the surface, it has low mineralization. As it percolates down to the groundwater surface, it may dissolve salt in the soil and/or may derive calcium and sulphate from the solution of gypsum in till. This water is hard and mineralized. As this water enters the bedrock (in a recharge area), a cation exchange usually occurs with the clay particles substituting calcium and magnesium for sodium. This softens the water and increases the mineralization even more. In discharge areas the water is relatively mature and may contain a significant concentration of dissolved constituents.

Appendix Table B4 provides a classification of dissolved inorganic constituents typically found in groundwater. These constituents are classified according to their concentrations. The categories are general and many types of natural groundwater exceed the concentration ranges. This table shows that some of the major constituents of groundwater are bicarbonate, calcium, chloride, magnesium, sodium and sulphate. On the other hand, metal ions such as chromium, manganese and zinc are typically trace constituents. Dissolved organics are present in natural groundwater but concentrations are much lower than those of the dissolved inorganic matter. Naturally occurring dissolved organics seldom make water non-potable. Note that many dissolved organic substances may be noxious at concentrations considerably lower than for dissolved inorganics.

5. ENVIRONMENTAL EFFECTS OF DRILLING WASTE DISPOSAL

5.1 EFFECTS OF DRILLING WASTE DISPOSAL ON SOILS AND PLANTS

The possible effects of drilling waste disposal on soil physical properties have barely been documented. A study of abandoned wellsites by the ERCB (1985) points out that poor reclamation success was more likely related to adverse effects on soil physical properties rather than on chemical properties. However, only standard fertility analyses were carried out in this study and a more conclusive assessment of the causes of poor reclamation success is not possible. Based on studies, observations and personal communications, Tucker (1985) concluded that the addition of drilling wastes containing clay can increase the water holding capacity, improve workability and reduce wind erodibility of sandy soils, but the same practice can reduce infiltration rates on medium and fine textured soils. The latter leads to ponding, increased runoff and erosion, deteriorated trafficability and possibly reduced available water holding capacity. Increased water holding capacity of sandy soils after land spreading has been reported by Forsgren-Perkins Engineering (1982). Land spreading of municipal sludges can lead to compaction and structural damage of soil which can be alleviated by the use of flotation tires (Environment Canada, 1984). Sludge application on frozen, ice-covered or snow covered soil is usually not recommended due to the high run-off potential.

Effects of the four major disposal methods on soil physical properties are related to mixing and compaction of the soil and lead to:

- change (degradation) of structure
- change in texture (dependent on stratification)
- increased bulk density
- reduced infiltration and permeability
- reduced aeration

Burying and trenching affect a relatively small area.

Squeezing and spreading require a larger area. In addition to possible textural redistribution texture becomes finer if clays are added. Spreading permits these effects to be more homogeneous and controllable, and therefore potentially less severe, than under the other methods.

The magnitude of the effects depends on soil type and weather conditions. In general, the effects are less negative, or even positive, on sandy soils as compared to clayey soils provided groundwater contamination does not occur. Compaction is reduced when the carrying capacity of the soil is high. This is the case when the ground is frozen or not too wet. However, run-off potential exists on frozen ground. Landspreading is best performed when temperature and moisture conditions favour microbial decomposition. Degradation is most rapid when temperatures are between 10° and 30° C and soils are moist but not wet (Peake et al., 1985). Further, nutrient and oxygen supply are important. Nutrients can be added as inorganic fertilizer. Fine textured soils are less aerated than coarse-textured soil which can be offset by more frequent tilling operations (Peake et al., 1985).

5.1.2 Effects on Soil Chemical Parameters

The effects of various methods of drilling waste disposal on chemical soil properties are poorly documented in the literature. A few studies on land spreading of drilling wastes have been conducted but no documentation on the effects of the other disposal methods were found in the literature. Some studies have investigated the effect of the whole fluids, others only look at individual components of drilling muds. Major findings are summarized below.

Salinity and sodicity have been identified most frequently as causing negative effects on soils when drilling wastes are added (Crabtree, 1985; Edwards, 1985; Foght, 1985; Forsgren-Perkins Engineering, 1985; Miller et al., 1980; Miller and Pesaran, 1980; Moseley, 1980; Nelson et al., 1984; Palmer, 1985; Smith and James, 1979; Strosher et al., 1980; Younkin and Johnson, 1980). This is not only the case with drilling wastes from salt water base systems, but also for freshwater mud or invert mud systems. Sodium, potassium and chloride are the chief inorganic contaminants of soil. Smith and James (1979) identified leaching and erosion processes to be the main mechanisms of contaminant spreading when the sumps were located on slopes, immediately adjacent to slopes or when overfilling of sumps and spillage occurred.

Trace elements in muds include barium, cadmium, zinc, chromium, lead, mercury and arsenic (Moseley, 1980; Nelson et al., 1984; Smith and James, 1979). The subjects of trace elements and heavy metals in the environment are very complex and each element has unique and complex behavior. Reaction processes have been studied and modelled and can be explained/predicted. What is needed is an understanding of the quantities present in drilling wastes, their form, their solubility, and an understanding of the presence of other chemicals they may react with.

A few examples that reflect the complexities follow. Chromium is very toxic in the hexavalent state but occurs mainly in the less toxic trivalent state, or is reduced to its trivalent state except when manganese is present in amounts slightly greater than that of chromium. When hydrophilic clays such as bentonite in freshwater muds are present, the elements tend to be adsorbed to the clay particles (Moseley, 1980). The effect of these elements in the soil depends on their solubility. When the pH is less than 6.5 the solubility of some metals increases; they may be mobilized and migrate to groundwater sources (Peake et al., 1985). Liming to maintain a pH above this level helps to reduce metal solubility. On the other hand, most heavy metals hydrolyze and can form charged (soluble) anionic species under alkaline conditions.

The poor documentation of which organics are added to sumps makes it extremely difficult to determine the fate and effects of organic constituents in drilling wastes. Foght (1985) indicates that xanthan gums are apparently persistent in soil but side chain cleavage occurs. Polyacrylamides are also resistant to microbial degradation in soil, but their presence can stimulate growth of certain aerobes. Cellulose and starch are easily degradable, starch more so than cellulose. Lignosulphonates tend to be more resistant than their parent lignin compounds which themselves are persistent. Many components of diesel fuel are readily degradable under aerobic conditions, but persistent under anaerobic conditions such as in waterlogged soil. Some of its low molecular weight components (e.g. benzene, pentane) may be toxic to microbes. In general, a voluminous literature exists regarding the metabolism of organic compounds. The main problem is the poor documentation of which organics are added to sumps.

Even though the wastes are contained at depth, burying and trenching may affect soil chemical properties by upward migration of mobile waste components, especially soluble salts. Becker (1986) indicates the potential for upward migration of buried wastes from invert mud systems with subsequent contamination of soil and surface water, but no data are presented.

Squeezing and spreading may cause changes in the following soil parameters:

- salinity (Electrical Conductivity; EC)
- sodicity (Sodium Adsorption Ratio; SAR)
- reaction (pH)
- content of soluble cations and anions
- cation exchange capacity (C.E.C.)
- content of toxic constituents such as:
    - trace elements, specifically heavy metals
    - decomposition products of organic constituents of drilling wastes

Squeezing (mixing of wastes primarily with B horizon material and subsequent topsoil cover) directly affects chemical properties of the B horizon and indirectly those of the topsoil layer by potential upward migration of waste materials.

Spreading (mixing of wastes primarily with Ah horizon material in Chernozems with LFH, Ae, B horizon material in Luvisols) directly affects the chemical properties of the topsoil. However, the wastes are contained at the surface thus enhancing degradation. Also potential problems may be recognized and corrected e.g. by the addition of fertilizer, irrigation, etc.

The magnitude of the effects differ with soil type. Salinity and sodicity effects are less severe on sandier textures (higher permeability) where salts can be leached out of the profile. However, a potential for groundwater contamination arises in such cases. An increase in cation exchange capacity and pH upon the addition of drilling waste could amend sandy soils (Palmer, 1985).

Clayey soils have a higher buffering capacity than sandy soils (Schroeder, 1978). This means they are less prone to changes in pH. Changes in pH can cause changes in nutrient availability to plants and solubility of trace elements, specifically heavy metals. If pH levels are increased there would be reduced solubility of many metals.

5.1.3 Effects on Plants

Drilling waste disposal indirectly affects plants which react to changes in the soil environment. Changes in physical characteristics such as soil structure and bulk density may reduce plant growth by impeding rooting behaviour and causing oxygen deficiency in the rooting zone. This effect is stronger in clayey soils than in sandy soils. On the other hand yields can increase on sandy soils when clay is added to improve water holding capacity and nutrient retention (Tucker, 1985).

Changes in chemical properties can entail yield reductions. Salinity increases above 2 mS/cm for trees (Edwards, 1985) and above 4 mS/cm for many other plants, depending on their salt tolerance, are likely to cause yield reductions. Sodicity impedes plant growth by creating a poor soil structure or through phytotoxic effects. Salinity and sodicity effects will be pronounced and persistent if the clay content and/or background salinity/sodicity of the soil are high and the climate is dry. On sandy soils, salts may be leached out but may contaminate groundwater. Salinity and sodicity have been identified as key chemical parameters reducing yields when disposing of drilling wastes (Miller et al., 1980; Miller and Pesaran, 1980; Strosher et al., 1980).

Analyses of drilling wastes (Appendix Table A5) as well as data from the literature suggest that key ions in the wastes are sodium, potassium, chloride and sulphate. Potassium and sulphate are major nutrient elements; chloride is needed in traces, while sodium may be beneficial to some plants (Finck, 1976). For each nutrient element there are levels of deficiency (yields reduced), optimum levels (yields optimum) and levels of toxicity (yields reduced). These levels vary with the type of plant, type of soil, and climate. Certain plants (e.g. Cruciferae family) benefit from increased chloride levels; other plants (e.g. Solanaceae family) show yield depressions with increasing chloride levels (Finck, 1976). Elements of special environmental concern are those non-toxic to plants at levels which are harmful to animals and humans such as cadmium and selenium (Environment Canada, 1984).

Miller et al. (1980) studied the effect of 31 drilling fluid components on growth of sweet corn and green beans in greenhouse pot studies. The authors found growth reductions due to salinity and sodicity caused by potassium chloride and sodium hydroxide; as well as due to possibly phytotoxic decomposition products of diesel oil, guar gum, a fiber mixture, starches and some lignosulfonates.

Nelson et al. (1984) determined plant availability of trace elements in drilling fluids prepared from different barites and evaluated chemical extractants for predicting plant availability of trace elements in drilling fluid-amended soils. Mercury, chromium and barite were essentially unavailable for plant uptake and concentrations of these metals were not related to the amounts in the rooting media. However, the uptake rates of zinc, copper, cadmium, arsenic and lead were directly related to the concentration of these elements in the soil-mud mixture. The method of determination (total element analysis, DTPA-extractable or acetic acid-soluble forms) did not influence the results.

5.1.4 Tolerable Levels of Waste Parameters/Constituents in Soils for Plant Growth

Tolerable concentrations of waste constituents in soil are difficult to generalize and vary depending on soil properties, topography, hydrogeology, type of crop, etc. The knowledge of such concentrations is important in order to establish permissible loadings of wastes which can be applied without damaging the environment. Analysis procedures for fluids, solids and soils are given in Appendix C1.

In general, data on loadings of waste constituents are very limited and should be established for various environments for drilling waste disposal in Alberta. Nevertheless, the "first approximations" given in the following provide a starting point based on what is known.

Soil Physical Properties

Guidelines used to evaluate suitability of surface materials for land reclamation are given in Table 5.1. Similar criteria for assessing soil structure, density, permeability and aeration, have not been defined.

Table 5.1 Criteria for Evaluating Texture of Surface Material (after A.S.A.C., 1981).

Parameter	Region	SUITABILITY			
		Good	Fair	Poor	Unsuitable
Texture*	Northern Forest and Plains	FSL, VFSL L, SiL, SL	CL, SCL SiCL	S, LS, SiC, C, HC	Bedrock
	Eastern Slopes	SL, FSL, L, SiCL SCL	CL, SiL VFSL	S, LS, C, HC	Consolidated Bedrock

* Regional differences reflect interaction between climate and soil moisture holding capacity.

Classes based on site and soil characteristics for sewage disposal have also been defined (Table 5.2). Note that textures of soils for ideal and inferior conditions differ in each rating system. Whereas, suitability for surface materials for reclamation, sewage sludge disposal and drilling waste disposal have several common attributes, ideal conditions for each are not necessarily the same. Waste disposal is probably most similar to sewage disposal, hence, the recommended class limits are very similar.

Table 5.2 Suitability of Sites for Sewage Sludge Disposal by Land Spreading (Alberta Environment, 1982).

	Acceptable[1]			Not Acceptable
Parameters	Class 1	Class 2	Class 3	Class 4
pH	≥6.5	≥6.5	≥6.5	≤6.5[2]
Texture (to at least 30 cm)	CL, SiCL, SiL, Si, SiC L, SCL, SC	C, HC	LS, SL	sand and gravel; stream valleys; intermittent drainage areas; organic soils
Slope %	0-2	2-5	5-9	>9
Depth to Potable Aquifer (m)	>5	3-5	2-3	<2

[1] A site falls into the poorest class (highest Class Number) represented by any characteristic.

[2] A site with a pH <6.5 which would otherwise be classed 1 or 2 may be upgraded by liming to pH 6.5 or higher.

Permissible mud loadings to maintain a suitable structure, consistence and texture in the upper 20 cm have been estimated to be approximately 10 cm for medium and coarse and up to 5 cm for finer materials (Appendix C2).

Organic Constituents

Data on decomposition products of organic compounds are available but data are lacking on the original organic compounds added. The production of decomposition products depends on the resistivity of a compound against microbial degradation. This is not only dependent on its chemical recalcitrance but also its physical rigidity (size, shape). A further major control on degradation products is aeration status of soils. Short chain aliphatic acids may accumulate in conditions of reduced aeration. They may be phytotoxic. Reaction of sump organic molecules or their degradation products with soil humus may prevent their movement, but at the same time increase their persistence. Such reactions of pesticides (especially aniline-based) are the subject of considerable current research (e.g. Berry, D.F. and Boyd, S.A., 1985). Diesel oil and crude oil are phytotoxic, but are degraded by volatilization, photo-oxidation and microbial activity when contained close to the soil surface and climatic and soil conditions are suitable.

Soil Chemical Properties

Tolerable levels in soils have been established for salinity, sodicity and soil reaction (Table 5.3); for revegetation and for metals disposed in sewage sludge (Table 5.4). Calculation procedures are given in Appendix C3 and C4.

Table 5.3 Salinity and Sodicity Criteria for Rating Soil Suitability for Revegetation (after A.S.A.C., 1981).

	CLASSES OF SUITABILITY			
Parameter	Good	Fair	Poor	Unsuitable
EC[1] (mS/cm)	<2	2–4	4–8	>8
SAR	<4	4–8	8–12	>12
Reaction (pH)				
Northern Forest	6.0–7.5	5.0–6.0 7.6–8.0	4.0–5.0 8.1–9.0	<4.0 and >9.0
Eastern Slopes	6.0–7.5	5.0–6.0 7.6–8.5	4.0–5.0 8.6–9.0	<4.0 and >9.0
Plains Region	6.5–7.5	5.5–6.4 7.6–8.5	4.5–5.4 8.6–9.0	<4.5 and >9.0

[1] Electrical conductivity of saturation paste extract.

Table 5.4 Maximum Permissible Cumulative Metal Loadings to Soils (kg/ha) (after Alberta Environment, 1982).

	B[1]	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Class 1[2]	10	1.5	100	200	0.5	25	100	300
Class 2	7.5	1.1	75	150	0.4	19	75	200
Class 3	5	0.8	50	100	0.2	12	50	150

[1] Hot water soluble; other elements based on total quantities.

[2] Classes correspond to those defined in Table 5.2.
Note: not more than one-third of the cumulative loading may be applied in a single application.

Levels of selenium, arsenic, cobalt and molybdenum are not specified for Alberta. Loadings of 2.8, 15, 30 and 4 kg/ha, respectively, of the above metals for soils in Canada are permissible (Environment Canada, 1984).

Permissible loadings of other elements such as potassium, sodium, chloride and sulphate have not been clearly established yet. The ERCB suggests that a maximum spread rate of 400 lbs/acre (450 kg/ha) of chlorides and 210 lbs/acre (230 kg/ha) of sulphates on a high quality Chernozemic soil. A downward adjustment for poorer quality soils is recommended.

Plant Tolerances to Wastes

Forest species are not as tolerant to salinity as agricultural crops. Salinity levels of <2 mS/cm have suppressed growth of conifer seedlings in nurseries on the prairies (Edwards, 1985). Salt tolerances of common coniferous and broadleaf species, shrubs, grasses and forages, and field crops are given in Table 5.5. Some species that are not native to Alberta but that are grown in shelterbelts and as ornamentals are included.

Crops can benefit from potassium levels between 500-1000 ppm (1200-2400 kg/ha) in the upper 20 cm (Norwest Labs, 1986). The data in Appendix Table B3 suggest that most soils in Alberta would be unaffected or could benefit from some additions of potassium. In order to raise levels to 2400 kg/ha, 1500 kg/ha of potassium could be added to the Brown soils, 1100 kg/ha to the Dark Brown soils, and about 1800 kg/ha to the Black soils and Luvisols.

Table 5.5 Salt Tolerance of Various Plants.

LOW <1500 ppm* (EC <2)	MODERATE 1500-3000 ppm* (EC 2-4)	HIGH >3000 ppm* (EC >4)
	CONIFEROUS SPECIES	
Red Pine	Tamarack	Jack Pine
Scotpine	Norway Spruce	Mugo Pine
White Pine	Juniper	Black Spruce
Colorado Spruce	White Cedar	
Balsam Fir		
	DECIDUOUS SPECIES	
Manitoba Maple	Birch Spp.	Mountain Ash
	Aspen	American Elm
	Bar Oak	Willow
	SHRUBS	
Hawthorne	Alder	Russian Olive
Dogwood	Buckthorn	Honeysuckle
Spirea	Forsythia	Lilac
		Caragana
		Chokecherry
		Mayday

LOW (EC <4)**	MODERATE (EC 4-10)	HIGH (EC >10)
	GRASSES/FORAGES	
Timothy	Perennial Ryegrass	Western Wheatgrass
Meadow Foxtail	Bromegrass	Canadian Wild Rye
Clover	Tall Fescue	Bermuda Grass
Sweet Clover	Reed Canary Grass	Salt Grass
Alsike Clover	Alfalfa	
Red Clover	Sweet Clover	
	FIELD CROPS	
Peas	Corn	Barley
Beans	Canola	
Flax	Wheat	
	Oats	
	Rye	

* concentration in saturated extract.
** note salinity limits differ for corresponding classes.

Source: Edwards, 1985; conifers, deciduous trees, shrubs.
Alberta Agriculture, 1985; grasses, forages, field crops.

Chlorides are a special problem in forested areas because trees belong to the group of plants that are sensitive to chlorides. Chloride toxicity symptoms in forested areas begin at 800-1500 ppm in the foliage of conifers but a relationship to chloride levels in soils has not been established.

Tolerance of some plants to chloride levels based on concentrations in soil extracts follow (California Fertilizer Association, 1980):

CROPS	CHLORIDE (me/l in saturation extract)	CORRESPONDING (kg/ha in soil)
Barley	90	4320
Wheat (young)	25	1200
Alfalfa	23	1100

Optimum levels under various conditions in Alberta have not yet been established (Norwest Labs, 1986; personal communication). Nevertheless, chloride additions of 700 kg/ha if incorporated into the upper 20 cm of soil should be tolerable, for trees other than conifers and agricultural crops, assuming that the initial chloride status of the soil is very low (this is true for most non-saline soils because EC levels are less than 0.2 mS/cm).

Sulphate-S concentrations over 20 ppm (50 kg/ha in the upper 20 cm) generally have been found to be of no benefit to soils (Norwest Labs, 1986; personal communication). Luvisols seem to be below these recommended levels and might therefore benefit from additions of 25-40 kg/ha of Sulphate-S in the upper 20 cm.

5.1.5 Limiting Constituents for Environmentally Safe Disposal of Drilling Wastes

Environmentally safe disposal has to aim at creating controllable situations when the wastes are disposed so that possible mistakes can be recognized and corrected. Based on our current knowledge about the characteristics of drilling wastes, the complexity of soil processes and interactions with groundwater, burying and trenching (deep and shallow) are not advisable. Burying wastes keeps them confined but it also may allow concentrated leaching into groundwater, and anaerobic decomposition may contribute to formation of highly noxious soluble substances. Squeezing is acceptable provided the solids are brought to the surface because the wastes are contained close to the soil surface.

Surface spreading of the wastes, a common method for disposing municipal sludges, is the most desirable option where sufficient area for spreading is available but might not be practical in all forested areas. Alternative treatment/disposal methods have to be considered in such cases (see Section 7.4).

The most limiting constituents for surface spreading of drilling wastes in Alberta have been estimated from very limited data on fluids and solids portions of sumps and common mud constituents (see Appendix C5). Based on high and low concentrations in sumps, a given volume and permissible loadings for these constituents, the area needed for environmentally safe disposal was calculated. Constituents which required a large area (>1 ha) for disposal were identified as the most limiting constituents. Based on permissible loadings outlined in the previous section (ERCB recommendations for Cl and SO_4; metal loadings for sewage sludge disposal (Alberta Environment, 1982); and estimated loadings for Na, K and clay) the most limiting constituents are:

1. Fresh Water Sumps
   - Cl, SO4
   - possibly trace elements and organics

2. KCl Sumps
   - K, Cl, SO4, total salt concentration
   - trace elements, organics

3. NaCl Sumps
   - Na, Cl, SO4, total salt concentration
   - trace elements, possibly organics

4. Invert Mud Sumps
   - hydrocarbons (oil, diesel, etc.) associated with solids
   - total salt concentration
   - trace elements, organics

Once a permissible loading is established it is easy to calculate the area required for surface disposal from concentrations and volumes.

(a) Known: concentration; volume; permissible loading
To be determined: area needed for disposal

Concentration (kg/m^3)* x Volume (m^3) = Amount to be Disposed (kg)**

$$\text{Area Needed for Disposal (ha)} = \frac{\text{Amount to be Disposed (kg)}}{\text{Permissible Loading (kg/ha)}}$$

* Concentration in mg/l or ppm x 0.001 = Concentration in kg/m^3
** For a volume of 1,000 m^3 the amount to be disposed (kg) = concentration in mg/l or ppm

For the "amount to be disposed" concentrations of fluids and solids have to be considered either combined or separate depending on whether both phases are disposed at the same site or not. A representative sample of both phases has to be gathered. For recommendations on sampling and analyses, see Section 7.1. The effect of organics is currently accounted for by the trout test or microtox test on the "fluids". These bioassays are not specifically geared towards plant toxicity, nor do they address the "solids", but at least they indicate possible general effects. Specific research on organics occurring in drilling wastes is urgently needed.

5.2 EFFECTS OF DRILLING WASTE DISPOSAL ON SURFACE WATER

5.2.1 Overview

Most of the environmental literature on drilling waste disposal concentrates primarily on terrestrial systems and secondly on groundwater impact.

Considering that direct surface water disposal is not allowed surface water contamination related to drilling activity could only occur as the result of:

1. Accidental release through sump or lease berm disruption.
2. Improper off-site drilling fluid disposal.
3. Leaching from disposal areas. This applies to fluids and solids.
4. Secondarily through surface water discharge of contaminated groundwaters.

To minimize any potential risk to the environment the ERCB has required that fluids for off-site disposal pass a Trout Toxicity Test, one of two trout fingerlings (3-10 cm) must survive 96 hours in treated fluid. Considering the complexity and diversity in drilling fluid components an overall aquatic toxicity evaluation is a regulatory control that can be easily implemented. But such testing does not address the effects of long term exposure to sub-lethal levels of contamination. Neither do these tests identify specific constituents which may be harmful in terrestrial systems.

5.2.2 Tolerable Levels of Waste Constituents in Surface Waters

The constituents which could cause surface water contamination can broadly be sub-divided into four categories 1) salinity and major ions, 2) suspended solids, 3) heavy metals, and 4) organic compounds. Relative amounts of these constituents in the drilling waste vary according to the mud system, geographic region and level of sump treatment.

Alberta has developed surface water quality objectives (ASWQO) (Standards and Approvals Division, 1977) which are designed to protect surface waters for all general uses (Appendix Table C4). They are not standards, and as such, have no legal status. They are basically guidelines to help focus water quality management activities. Water quality varies substantially throughout Alberta (see Section 4.2) and as such some water bodies naturally exceed the ASWQO.

Salts are of major concern with respect to drilling wastes, however, the ASWQO do not contain an objective for TDS or major ions. They only state that Na should comprise between 30 and 75% of cations. The Canadian drinking water guidelines (Health and Welfare Canada, 1978) include a maximum acceptable level for TDS of 500 mg/l, and an objective for sulphate of <150 mg/l. Sodium levels in excess of 20 mg/l are of concern to individuals with heart disease. The range of pH is to be 6.5-8.5, but not altered by more than 0.5 pH units. Like pH, the suspended solids objective is based upon relative change from background.

Maximum concentrations for heavy metals and a few organic compounds are given in the ASWQO. Oil and grease are to be absent and phenolic compounds must be less than 0.005 mg/l. There is no general toxicity requirement in the ASWQO.

Environment Canada has recently published guidelines for surface water quality (Inland Waters Directorate, 1979) that deal in greater detail than the ASWQO with specific constituents, especially trace metals. Recreational water quality guidelines have been produced (Federal-Provincial Working Group on Recreational Water Quality, 1983) and are the first attempt in Canada to produce water use specific guidelines. Other water use specific criteria have been published (McNeely et al., 1979) but have not been generally applied in Alberta.

5.2.3 Surface Water Contamination Risk

Potential surface water impact related to drilling depends upon 1) constituent solubility and 2) environmental sensitivity. Solubility is of importance because aqueous overland flow is the primary mechanism by which drilling wastes will reach a lake or stream. Environmental sensitivity is based upon the known aquatic toxicity of constituents. Direct waste discharge to surface waters is not allowed in Alberta.

Each of the major drilling waste constituent categories are reviewed here with respect to the two factors defined above:

Salts

Runoff during offsite disposal, or subsequent leaching, could cause surface water contamination. At moderate concentrations salt loadings do not pose a major threat to aquatic systems. Total dissolved solid concentrations generally have to exceed 4000 mg/l before fish toxicity is apparent (Strosher et al., 1980), however, a balance between monovalent and divalent ions seems to be important (Shaw, 1985). In Alberta surface waters most often have natural TDS levels less than 500 mg/l, and calcium bicarbonate is the dominant salt. Calcium bicarbonate loadings generated by fluids disposal might increase alkalinity, however, the natural buffering system should result in rapid equilibration. The same applies to pH in most areas of Alberta. Sodium, sulphate and potassium levels in surface waters vary substantially, and loadings would have to be established depending on background levels. Maximum concentrations are observed in saline sloughs and lakes in southeastern Alberta, while mountain runoff tends to have very low sodium and sulphate concentrations.

Suspended Solids

Bentonite and barite are major components of drilling mud and consequently drilling waste. At high concentrations they can coat the gills of fish and cause suffocation. The high adsorption potential of bentonite and barite enables these materials to scavenge heavy metals and trace organics.

Heavy Metals

Drilling wastes are known to have elevated concentrations of barium, cadmium, zinc, copper, chromium, lead, mercury and arsenic (Abouguendia et al., 1985; Canter, 1985). Heavy metal salts are added to prevent microbial degradation. In the dissolved form heavy metals can be extremely toxic. Toxicity and leachability are reduced in high pH systems due to adsorption, ion exchange, chemical precipitation and complexation with organics (Canter, 1985). Hexavalent chromium (Cr+6) is a major component of chromelignosulfonate. Hexavalent chromium tends to be converted to less toxic chromates (Cr+3) in the presence of organics, lignosulfonates, lignites and high temperatures. While Cr+6 usually reduces to Cr+3 in the presence of ferrous iron, manganese is known to prevent this reduction and where Mn is present in amounts slightly greater than that of Cr, the oxided form of Cr persists. Most heavy metals associated with drilling tend to concentrate in the muds. Their toxicity should be minimized by neutral to high pH levels, however, they can form charged (soluble) anionic species under alkaline conditions.

Trace Organics

Organics are used extensively in the drilling process and are of major environmental concern. The major organic components are polymers, and lignosulfonates. These are extremely general terms: more detailed information is needed to understand the role and fate of organics. Hydrocarbons, like diesel oil are used for lubricants. Transport and fate of organic contaminants depends upon transport in the water phase, volatilization, adsorption to soil, incorporation into microbial or plant biomass and bacterial degradation. Higher molecular weight organic constituents are relatively non-toxic, whereas low molecular weight constituents have toxicities ranging from relatively low to high (Strosher et al., 1980). As such the hydrocarbons are the most toxic component. Lignosulfonates have moderate toxicity.

Nutrients

Nutrients of relevance to surface waters in drilling wastes are nitrogen and phosphorus. Phosphates tend to stimulate weed and algae growth in lakes and streams. However, they have a high tendency to adsorb to particulates and thereby be removed from the dissolved phase. Ammonia is readily adsorbed by aquatic plants but it is toxic to fish. Ammonia toxicity is enhanced at high pH levels and elevated temperatures. Ammonia is highly soluble and therefore has a high potential for transport in surface runoff.

In summary, the highest risk to surface water systems from disposal of drilling wastes centres on the fluid component. Trace metals and toxic organics tend to be removed from the fluids during treatment which causes concentration at the bottom of the sump. The hydrocarbons are very toxic but are largely eliminated during surface skimming. High molecular weight organics and noxious metals are precipitated into the muds. Although salts remain in the fluids their toxicity threshold is high. Implementation of appropriate fluid disposal procedures should minimize the salt toxicity risk.

Of the four solids disposal procedures 1) in pit burial, 2) deep or shallow trenching, 3) standard squeezing, and 4) surface spreading, the latter tend to disperse the wastes on the surface and thereby enhance the surface runoff impact potential. This potential will depend upon soil texture, topography and climatic conditions. Detailed studies on surface runoff have not been carried out to date, however, in most instances the benefits to organic degradation probably outweigh the surface runoff impact risk.

5.3 EFFECTS OF DRILLING WASTE DISPOSAL ON GROUNDWATER

Groundwater may take a few weeks to a few years, or more, to flow from a waste disposal site to a nearby water supply source. This is typically much greater than the time it takes for surface water to flow a comparable distance. Therefore, contaminated surface water is often detected long before contaminated groundwater. Also, since groundwater flow is below the ground surface, contamination signs are more difficult to observe. For these reasons, hydrogeology is frequently not considered when disposing of wastes either on or below the ground surface. However, recent events in the U.S.A. show that wastes which were buried and forgotten for decades have contaminated many important potential groundwater supply sources. As the cost of removing this water is high, and also because of possible future litigation, groundwater conditions should be considered when disposing of drilling wastes.

5.3.1 Principles of Contaminant Migration

Constituents that are transported by groundwater (for theory of groundwater flow, see Appendix B3) from a drilling waste disposal site can be classified as dissolved (solutes), suspended solids (colloids), or oils (immiscible liquids). The most important of these constituents are the dissolved species which include heavy metal ions, because these have the potential to travel and spread much farther than the suspended solids or oil.

Dissolved Contaminants

The dissolved species which are carried by groundwater can be described as either reactive or non-reactive. Those that are non-reactive travel farther in groundwater. Examples of some non-reactive contaminants are chloride, sulphate and nitrate. Examples of some reactive contaminants are heavy metals.

The primary physical processes which transport contaminants are advection and chemical dispersion.

The primary chemical processes which affect the transport of dissolved contaminants in groundwater are retardation and molecular diffusion.

Often the above physical and chemical processes act to naturally rejuvenate groundwater. While advection will transport contaminant in the direction of groundwater flow, the combined effects of dispersion, diffusion and retardation will reduce its concentrations. The retardation of constituents is an especially important mechanism in deposits with a high clay content.

The effects of the rejuvenating processes are difficult to quantify without extensive laboratory and field testing. The migration of contaminants is further complicated by the differing densities of individual constituents, which leads to a separation during migration. For these reasons, the rejuvenating processes cannot be readily used when calculating distances that contaminants can travel or acceptable levels of contamination in the disposed waste. Instead, any such calculations of contaminant transportation are commonly based on advection rates and the rejuvenation is considered a positive, but unspecified, benefit.

Suspended Solids

The transportation of suspended solids in groundwater is usually a very local phenomenon. Due to the relatively large size and weight of such particles, they are naturally filtered out by the pores of subsurface materials. This mechanism is heavily relied upon when completing water wells, where over time the turbidity of water will decrease in response to the trapping of sediments in interstitial pores.

Oils

The movement of oil (hydrocarbons) in groundwater is a special problem because oils are typically less dense than, and are immiscible in water (Freeze and Cherry, 1979). Some types of oil, particularly polar compounds such as methanol, are soluble in water (Mackay et al., 1983). The movement of these can be described in the same way as other dissolved constituents. On the other hand, oil that is more dense than water and quite viscous is relatively immobile under ordinary hydraulic gradients.

Since light oil is less dense than water, it tends to migrate laterally along the top of the groundwater surface and does not penetrate this surface. Below a certain degree of saturation, oil is considered relatively immobile. Also, oil is readily biodegradable in a near surface oxygen-rich and bacteria-rich environment. For these reasons, the movement of oil is not a large scale problem provided that the quantities involved are small.

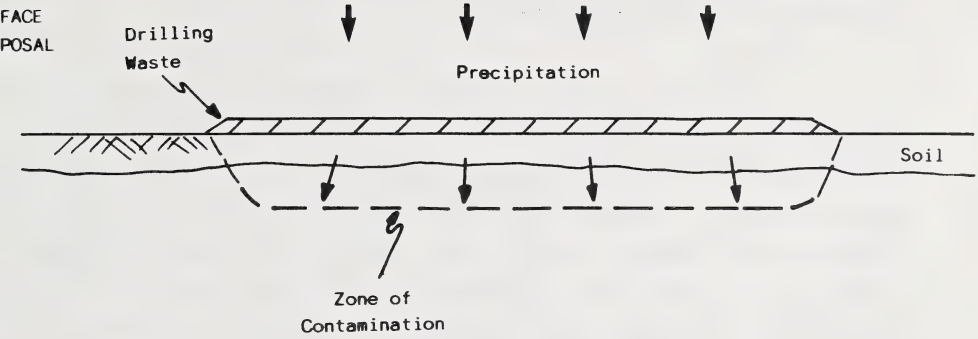
5.3.2 Effects of Drilling Waste Disposal on Groundwater

From a groundwater point of view, the drilling waste disposal methods can be divided into two basic types. The surface spreading (landfarming) and squeezing methods involve waste disposal over a relatively large area (see Figure 5.1). On the other hand, the burial and trenching methods involve disposal in a relatively small space below the soil zone. Contaminants in both cases reach the groundwater as either filtrates or leachates.

In the case of surface disposal any contamination is partially mitigated by microbiological processes in the upper soil zone. Also, any contamination will interact with a greater quantity of both surface and groundwater, thereby providing more dilution. For these reasons, surface spreading may be considered preferable assuming that the waste meets tolerable levels before disposal.

The contents of sumps to be disposed are extremely variable due to the nature of materials placed into them. Not only are different types of drilling mud (in different quantities) deposited, but sundry drilling by-products, such as spent diesel fuel and lubricating fluids, are also disposed of in these pits. The result is that a specific or quantitative chemical breakdown of a typical sump is not possible. However, many deleterious, inorganic constituents have been identified and are listed in Appendix Tables A5-A9. Some examples of these constituents are chromate, lead and sulphate.

A. SURFACE DISPOSAL



B. SUB-SURFACE DISPOSAL

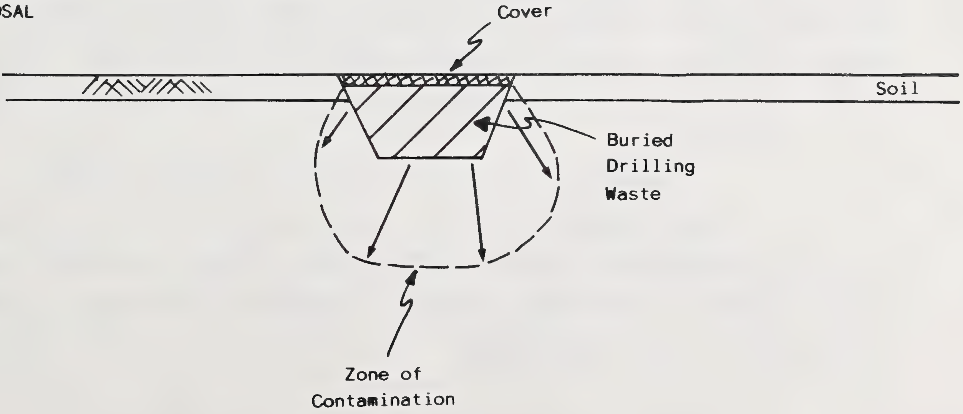


Figure 5.1 Surface and Subsurface Disposal.

Current literature on groundwater contamination mainly discusses the toxicity and transportation of dissolved inorganic constituents in drilling waste.

Collins (1975) provides a breakdown of inorganic constituents in drilling fluids based on the type of geologic system drilled. Although most of the constituents analyzed are naturally present in groundwater, several had high concentrations relative to natural groundwater levels in all the systems. These included the anions chloride, bicarbonate and sulphate and the cations sodium, potassium, calcium, magnesium and manganese. Canviro Consultants Ltd. (1983) analyzed trace substances in petroleum industry sludges. They reported presence of heavy metals such as copper, chromium and zinc at high concentrations. Such constituents are in agreement with Appendix Table A7. The correlation of elevated levels between the different geologic systems indicates that it is the drilling mud, and not the subsurface material, which contains the high concentrations of these constituents.

Beak Consultants Ltd. (1981) found heavy metals to be of concern when sludges were landspread at Canadian petroleum facilities. Because of the toxicity of these elements and the unknown long-term fate of these constituents the author recommended monitoring of groundwater for heavy metals.

The solubility and therefore mobility of heavy metals (cations) is also influenced by anions in the groundwater (Matthess et al., 1985). These anions will form complexes with the heavy metals that are of a variable solubility.

Murphy (1985) compared two drilling fluid disposal sites situated upon till and upon a higher hydraulic conductivity glacio-fluvial (outwash) deposit, respectively. Results of site surveys indicated that there was a leachate plume at both sites; little contaminant migration occurred through the till, but large movement through the glacio-fluvial deposit. Murphy also states that there was a great reduction in the concentration of certain major ions and trace metals in the unsaturated zone beneath the disposed waste.

Bost (1985) monitored levels of heavy metals and other parameters in groundwater near drilling waste disposal sites and found elevated levels in the groundwater down-gradient from the impoundments. Also, seasonal variations in the groundwater regime were found to influence the concentrations of certain ions, such as chloride. Therefore, seasonal changes must be monitored and taken into account when analyzing contaminant migration.

Work on dissolved organic constituents is rare. Ptacek et al. (1984) showed that the sorption characteristics of the aromatic hydrocarbons benzene, toluene and xylene are inversely related to their solubility in water. Since these compounds have high solubilities, they are less prone to sorption and are therefore relatively mobile. This indicates that some dissolved organic species are capable of travelling large distances. Duke and Parrish (1984) found that diesel fuel and mineral oil were correlated with toxicity of drilling fluids to marine organisms.

5.3.3 Tolerable Levels of Constituents in Groundwater

Tolerable levels of constituents in groundwater are set according to acceptable limits for human consumption. This is because the major and most sensitive user of groundwater is man. Other levels for agricultural purposes are less stringent and less well defined.

Maximum acceptable concentrations are defined in the Canadian Drinking Water Quality Guidelines (Appendix Table C5). A recommended procedure would be to analyze for these parameters and treat or dilute accordingly. Sump constituents that are often below maximum acceptable concentrations are sodium, potassium and bicarbonate (see Appendix Tables A5-A9). Sump constituents that may exceed maximum acceptable concentrations include chloride, sulphate, boron, barium, cadmium, iron and the heavy metals, copper, chromium, lead, manganese and zinc (see Appendix Tables A5-A9). Further, levels of arsenic, mercury, nitrate and the pH, hardness and total organic carbon (TOC) are often anomalous. These are therefore specifically recommended for analysis and treatment. The levels of chloride, nitrate and sulphate are of particular importance because these are relatively non-reactive constituents and may therefore travel longer distances in a groundwater system.

A good indicator for the presence of toxic organic constituents is the 96 hour trout bioassay. Although this test does not identify specific organics it indicates their presence in general. The test also does not account for mutagenic or carcinogenic effects which may be important if contaminants reach potable water sources.

The background concentrations of constituents in the groundwater is an important consideration when disposing of waste. Concentrations may exceed the acceptable levels of the Drinking Water Guidelines, for example, levels of chloride in mature water (found in discharge areas), or of sulphate in till can be locally high. Where background concentrations are greater than the drinking water guidelines, it may be permissible to dispose of drilling waste at levels equal to the background.

5.3.4 The Impact of Drilling Waste on Groundwater Quality

When disposing of drilling waste, it is necessary to consider the entire watershed because contaminants migrating in groundwater may be in transit for long times and may travel large distances. Also, it is very difficult and expensive to renovate polluted groundwater. Therefore, every attempt should be made to mitigate both the pollutant migration and the contamination in the disposed waste itself before disposal.

The impact of contaminants in the waste can be mitigated by testing for those constituents outlined and diluting the waste to meet these criteria. Specific attention should be given to heavy metals and dissolved organics as these constituents are particularly noxious, even in small concentrations.

In order to minimize the transportation of contaminants, waste can be contained in lined pits or spread over low hydraulic conductivity soil, such as clay till or lacustrine clay. The pits can be lined with plastic or clay. The clay helps to retard the movement of reactive constituents such as heavy metals. Disposal sites should not be located near aquifers. Of particular importance are buried valley aquifers and water sources in outwash deposits because these are relatively shallow and often used for domestic water supply purposes.

Accurate monitoring of the effects of drilling waste disposal on groundwater requires a site-specific groundwater observation system which monitors changes in hydrochemistry over time. This is necessary because the background groundwater chemistry, the groundwater flow regime and hydraulic conductivities are different at each disposal site.

A monitoring system consists of an array of piezometers. The piezometers are located throughout the disposal site and are also installed in the underlying geologic units. There are several types of piezometers, of which the standpipe piezometer is the most useful as it permits both the measurement of water levels and the sampling of water. A standpipe piezometer is similar to a small diameter well in which the casing has been sealed from above the screen to the ground surface, thus permitting only waters from the completion zone to enter the well.

By measuring the level of water in the piezometers, the distribution of hydraulic head in specific geologic formations can be measured. In this way the direction and velocity of groundwater flow (and, hence any contamination) can be determined. Also, local aquifers are then identified and background measurements of the hydrochemistry can be taken. It is important to install the monitoring system before the disposal of waste begins in order to provide a baseline set of readings. Additional piezometers can be added if necessary at a later date to further define a contaminant plume.

The monitoring system defines seasonal variations in the local groundwater regime. This facilitates an understanding of any contaminant plumes. When sampling groundwater for contaminants such as trace metals and organics, the procedures outlined by Gillham et al. (1983) should be followed. The cost of a groundwater monitoring system is small in relation to the expense of drilling an exploration or production well for oil. A monitoring system would not be necessary for low volume temporary sumps that are well-contained. For high volume, longer term sumps such as central sumps, a monitoring system is considered necessary.

6. ASSESSMENT OF WASTE DISPOSAL GUIDELINES

At present there are five documents with appendices regulating and guiding drilling waste disposal. The criteria used in each document for determining acceptable treatment/disposal options are listed next and their technical implications are evaluated by the Consultants.

1. **ERCB Interim Directive ID-OG75-2 "Sump Fluid Disposal Requirements" (See Appendix D1).** This document provides sump fluid disposal standards for subsurface disposal and on lease and off lease disposal of drilling fluids which all operators have to comply with province-wide. Criteria and technical implications are summarized in Table 6.1.

2. **ERCB Interim Directive ID 81-1 "Subsurface Disposal of Drilling Fluids" (See Appendix D2).** This docuement gives criteria for subsurface disposal which is given in Table 6.2

3. **"Guidelines for Sump Fluid Disposal on Crown Land - White and Yellow Areas" - 0799G for Public Lands Division Staff (See Appendix D3).** These guidelines were developed following a transfer of responsibility for surveillance of drilling waste disposal on public lands from the ERCB to the Public Lands Division of Alberta Energy and Natural Resources in 1983. In general, the guidelines state what was summarized in Table 6.1 for the ERCB guidelines. Additional points are summarized in Table 6.3.

4. **ENR Information Letter 82-5 "Potassium-based Drilling Mud Systems" (Appendix D4).** This document was issued following increased use of KCl mud systems which generate large volumes of highly concentrated saline drilling mud which is toxic to animals and plants. The K component cannot be removed at present.

Table 6.1 Criteria and Technical Implications for Subsurface, On Lease and Off Lease Disposal of Drilling Fluids.

Disposal	Criteria (from Document)	Implications (Pedology Consultants Technical Evaluation)		
		Strong Points	Weak Points	Improvements Recommended
Subsurface Formation	- approval by ERCB	- control/suveillance	-	-
	- subsurface formation not locally productive for oil or gas	- energy and resource conservation	-	-
	- TDS[1] > 20,000 mg/l in formation water of disposal zone	- resource conservation	-	-
On Lease	- notification of ENR or ERCB office 1 week before disposal	- surveillance	- does not state that approval is required; period of one week may be too short	- approval rather than notification should be required; a period >1 week would leave more time for surveillance
	- entire sump contents confined to lease	- tries to eliminate damage on areas not subject to the liabilities of the oil company	- does not encourage treatment or disposal of hazardous constituents elsewhere	-
	- sump volume <6,000 bbl; approval for >6,000 bbl	-	- concentration and toxicity not addressed. Sump with less than 6,000 bbl can be a problem	- volume alone should not be a criteria for on lease disposal, rather concentration, toxicity, waste loading and permissible loading; sumps <6,000 barrels should also be tested
	- lease >300 feet (100m) from normal high water mark of a water body, permanent stream or potable water well	- to protect surface and groundwater resources	- distance is not far enough in sensitive areas	- a larger buffer should be considered if: - major stream or river used for domestic supply or fishery - slope is considerable - runoff potential high
	- lease capable of accepting sump contents without runoff based on opinion of surveillance agent	- prevents contamination of lease and erosion	- does not address subsurface contamination - subjective assessment of lease capacity - does not require determination of parameters indicative of lease capacity such as infiltration rates, hydraulic conductivity	- possible groundwater contamination and runoff potential should be evaluated based on more more objective evaluation of the lease capacity; land farming procedures must be considered
Off Lease	- sump volume >6,000 bbl	-	- volume alone is not a criteria to assess potential environmental damages	- sumps <6,000 bbl might also warrant off lease disposal

Table 6.1 Criteria and Technical Implications for Subsurface, On Lease and Off Lease Disposal of Drilling Fluids (Continued).

Disposal	Criteria (from Document)	Implications (Pedology Consultants Technical Evaluation)		
		Strong Points	Weak Points	Improvements Recommended
Off Lease (Continued)	- sampling^2 and analysis^2 of sump contents	- objective way to assess problems	- sampling equipment, laboratory procedures reporting methods not clearly stated	- sampling equipment, laboratory procedures and reporting methods should be standardized and deviations documented for each site
	- if necessary, treatment of the sump to comply with 5 criteria: CL $\leq$1,000 mg/l SO4 $\leq$2,000 mg/l TDS^1 $\leq$4,000 mg/l pH 5.5-8.5 Trout Survival^3 96 hours trout test	- objective way to assess some of the major limiting constituents in sumps as well as to assess complex toxic effects of organics and inorganics	- elements other than chlorides or sulphates may be a problem - only fluids addressed, not solids which might be even more concentrated especially after treatment - not only concentration but total loading (volume x concentration) important from environmental point of view	- other elements such as sodium, potassium and trace metals might be limiting factors - it might be better to establish permissible loadings of most limiting factors in various environments
	- approval by surveillance based on: - description of sampling and treatment methods - analysis results of a representative sample	- control - objective assessment of waste characteristics;	- a statement of how to evaluate lab and treatment procedures is not included	- standards for lab and treatment procedures as well as for interpretation of results would make surveillance task easier
	- location of disposal area and sump volume - brief description of area and vegetation e.g. forested, wetland, etc.	- some assessment of the receiving environment	- assessment is subjective	- specific criteria of how to assess suitability of waste disposal should be given
	- landowner's permission if disposal to private land	-	-	-
	- disposal to open water body generally not permitted	- prevents direct loading	-	-

---

[1] Total Dissolved Solids.

[2] Collection of a representative sample composed of 18 subsamples in a glass or plastic container is required by dividing the sump into 6 segments; samples near the surface, middle and bottom of each segment are to be taken; minimum sample volume is 2 quarts (Appendix A of ID-OG75-2). Analysis is to be performed at a reliable commercial lab (Appendix A of ID-OG75-2). Methods to be used or a listing of reliable labs is not given.

[3] Guidelines for fish toxicity tests are given in Appendix B of ID-OG75-2.

Table 6.2 Criteria and Technical Implications for Subsurface Disposal.

Criteria	Strong Points	Weak Points	Improvements Recommended
- approval by ERCB	- control, surveillance	-	-
- disposal zone depth ≥600 m zone to 600 m has to be protected by casing or otherwise disposal through drill pipe annulus	- to avoid contamination of potable aquifers	-	-
- resistivity of formation water <0.33 OHM.M corrected for 20°C (≯20,000 mgl)			
- no oil or gas resources within 2 km of intended disposal well	- energy and resource conservation	-	-

Table 6.3 Additional Criteria to ID-OG75-2 for Public Lands Division Staff and Their Implications.

Disposal	Criteria	Strong Points	Weak Points	Improvements Recommended
On Lease	- Volumes <6,000 bbl do not require test, but officer can delay disposal until lease capacity assessed	- Same additional safety factor for on lease disposal	- Subjective assessment of environmental problems associated with waste disposal	- Sumps <6,000 bbl should also be tested
Off Lease	- Check sampling from well-mixed sump or pump off of treated sump	- surveillance	-	-
	- Spread rates for chlorides (400 lbs/acre) and sulphates (500 bbl/acre of fluid) are given	- Spread rates seem to be within safe limits	- Spread rates do not distinguish between various soil conditions and gaps; spread rates for other elements such as sodium, potassium are not addressed	- Permissible spread rates for various limiting sump constituents under various environmental conditions should be established
	- Formulae for calculating sump volume and lease capacity are given	- addresses physical capacity of lease area	- does not address permissible loadings (physical and chemical capacity of the lease area)	- permissible loadings for various environmental conditions should be established

No specific criteria are given, but the document recommends the submission of a disposal plan prior to the commencement of drilling. Subsurface disposal as a disposal option for KCl muds is encouraged.

Based on the characteristics of these wastes their use should only be allowed after a disposal plan has been accepted by the surveillance agency prior to drilling.

5. **Oil and Gas Regulations, R-57 (Rev. 33:2/81) "Care of Well Sites and Battery Sites" (Appendix D5).** This document addresses the environmentally safe disposal of "liquid wastes" such as drilling fluids and "waste material" such as rubbish, water or drilling fluids. The premise is that no pollution of air, soil, surface water or underground source of potable water must occur. Criteria given and their implications are summarized in Table 6.4. Solid wastes such as solids in a sump pit are not addressed.

The existing guidelines address the fluids components of drilling wastes, but not the solids. Many decisions are based on the discretion and subjective judgement of the field officer rather than objective criteria. The time frame in which many of the decisions have to be made is tight. Currently, a proposed set of guidelines replacing ERCB Interim Directives ID-OG75-2 and ID 81-1 are under review. These guidelines not only address drilling fluids but also solids. Testing of all sumps and drilling fluids is requested. A trout or microtox bioassay can be used for testing biotoxicity. Solids are to be spread over and worked into the lease, but burying and trenching are prohibited.

In the Consultants' opinion, the proposed guidelines address many of the concerns associated with drilling waste disposal to date.

Table 6.4 Criteria for Environmentally Safe Disposal of "Liquid Waste" and "Waste Materials" Outlined in the Oil and Gas Regulations.

Criteria	Strong Points	Weak Points	Improvements Recommended
- containment of waste at all times	- avoids runoff and pollution of adjacent areas and water bodies	- no punishment for violations	- penalties for pollution should be defined and enforced
- approval of disposal has to be given	- control, surveillance	-	-
- sufficient pit capacity	- avoids runoff and contamination of nearby areas and water bodies	-	-
- location and construction of pit so that no natural runoff water collected	- avoids dilution, increased volumes, contamination of underground water sources	-	-
- if conditions do not allow construction of a pit according to the above premises then wastes have to be stored in tanks	- avoids contamination	-	-
- wastes must not constitute safety hazard or nuisance	-	-	-
- upon completion, all liquid wastes must be disposed; debris must be cleared out	- requests disposal of wastes	- does not specify disposal of solids componented	- solids component should be addressed
- wastes can be disposed off lease, if no contamination of soil and water	- allows off lease disposal as an alternative as long as no soil or water resources are contaminated	-	-

7. MITIGATION MEASURES

The effects of drilling wastes on the environment can be alleviated by increased awareness of operators, responsible handling of the wastes and co-operation between operators and the surveillance agencies. Currently, there are many unanswered questions with regard to environmentally safe disposal of the wastes. Research is needed (see Chapter 8) to improve understanding and to create a sound base for developing disposal criteria.

Immediate practices to be considered for mitigating the effects are proper sampling and analyses techniques, treatment of sumps where necessary, cleaner working conditions and conscientious handling of the sump fluids on lease, foresight and planning, and development of a waste management plan particularly in areas of high drilling density. Recommendations for each of these points are addressed next.

7.1 SAMPLING AND ANALYSES

Representative samples must be collected. Interpretation of non-representative samples can be very misleading and can create management problems for field staff. Sump sampling methodologies and equipment should therefore be standardized.

For collecting representative samples a composite sample from various areas of the sump and all depths (fluids and solids) should be taken. This could be done using a dingy or from the edge attaching equipment to a pole or line. Standard samplers used for collecting lake or river sediments are the Eckman Bottom Sampler or Ponar Bottom Sampler. The Van Dorn Sampler is used for collecting discrete areas in a water column, whereas, the Lund Tube Sampler collects integrated samples throughout the water/sediment column. Depending on what kind of sample one wishes to obtain, any one of these samplers can be used. For initial characterization of the sump, the Lund Tube Sampler is probably the best device. If a sump requires treatment which is likely to change the composition of the solids portion, then the solids portion should be resampled before disposal. Tests comparing total (fluids plus solids) sump analyses with analyses of solids after treatment may be warranted in order to establish how much treatment changes the initial results.

Based on what is known to date about sump characteristics, it would be desirable that all sumps be sampled and analyzed, not only those over 6,000 bbl. From analytical data (see Appendix Table A5) evaluated so far it is obvious that sumps with volumes of less than 6,000 barrels can be toxic to aquatic life, potentially contaminate aquifers or be damaging to soils and plants. If sump analysis data are not available a log of potentially noxious constituents brought on site for drilling purposes should be kept and made available to the field staff.

The trout or microtox bioassay are the best available for aquatic systems and cover the area of complex unknown lethal effects of inorganic and organic constituents in the sump. Sublethal effects are not accounted for and should be considered in the future. Also, these tests are not applicable to the protection of soils and vegetation. Other required analyses are salt content (total dissolved solids), relationship of soluble sodium to calcium and magnesium (Sodium adsorption ratio which can be directly calculated from the concentration of these ions which are routinely determined), concentration of chlorides, sulphates, potassium and sodium, pH, texture, heavy metals and trace elements. Analytical methods for the fluids should be those applied by the ERCB. Methodologies for sludges could be those used for soil samples. Analytical procedures to be used and the method of reporting should be standardized by the ERCB to make comparison of results easier (recommended procedures are listed in Appendix C1).

7.2 TREATMENT

If the properties of the wastes are potentially damaging to soils, groundwater or surface water the wastes should be treated, regardless of their volume. Acceptable treatment procedures should be standardized by the ERCB, and distinguished from nonacceptable treatment procedures to facilitate the task of field officers who have to judge proposed treatment procedures (ERCB Interim Directive ID-OG75-2). Treatment procedures should aim at reducing concentration of noxious constituents in fluids and solids portions of the sump.

Efforts to develop technologies which reduce waste volumes and/or toxicities have been made in the waste treatment industry. Conventional treatment procedures involve separation of oil and water, of the fluids and solids phases, as well as detoxicification of the clarified water phase, and pH adjustment (Specken, 1985). Separation of fluids and solids is performed with inorganic and organic flocculants such as gypsum and polyacrylamides, respectively.

Detoxification involves the use of activated carbon to adsorb noxious organic compounds. An oxidative step with potassium permanganate prior to the carbon treatment may be needed (Spectra Water Processes, Ltd., 1985). Concentrated sulphuric acid is used for pH reduction. These processes can be performed on site. They do not lower the initial chloride content of the water (Specken, 1985). While they may render the fluids portion ready for disposal, the solids portion may become more concentrated with former contaminants of the fluids portion.

Neyrfor Canada Ltd. (1986) has developed a treatment unit which works according to similar principles as those indicated above. The treatment can be performed on site. It theoretically yields a clarified fluid which can be pumped off and a sludge containing 40-60% water. Again, the sludge is enriched with all the contaminants precipitated from the fluids portion. The company advertises the suitability of the sludge for surface spreading. Before incorporation, the sludge can be dried. A two to three feet thick layer of sludge can be dry within several days.

Hitech Research and Development Inc. has experimented with chemically enhanced centrifuging (Becker, 1985). This process reduces the fluid volume by removing cuttings from the drilling fluid during the drilling operation. The drilling fluid can be recycled and reused and altogether less fluid is discarded into the sump pit.

Whittaker (1986) reports on the use of membrane technology in the oil industry. The technique of ultrafiltration allows removal of large quantities of suspended solids. Reverse osmosis facilitates both removal of salt and oil/water separation. This technique has been patented in the United States by ROMEC and is used to desalinize water from sump pits. The system can reduce the salt concentration of a brine from 35,000 mg/l to 350 mg/l. A mobile unit, combining ultrafiltration and reverse osmosis, is available in Alberta from the Environmental Emergencies Technology Division of Environment Canada (Whittaker, 1986).

7.3 HANDLING OF SUMPS

Careful and clean working conditions during and after drilling should be encouraged especially in sensitive areas. Accidental spills probably pose the most severe impact to lakes and streams. Dyke construction methods should be designed to prevent accidental spills through breaching. Treatment and disposal may be facilitated by separation of sump fluids.

Placement of wastes in permeable materials should be avoided under all circumstances in order to avoid groundwater contamination. The placement of wastes in areas surrounded by clay till or lacustrine clay, or in lined pits are the best alternatives. Disposal in areas with near surface groundwater, in recharge zones, or above shallow aquifers should be discouraged. Buried valley aquifers and aquifers in outwash deposits should also be avoided because these are important sources of domestic water.

7.4 DISPOSAL ALTERNATIVES/WASTE UTILIZATION

Specific site characteristics have to be considered in final disposal, namely: site topography, proximity to an open water body, distance to the groundwater surface, texture (and implicitly permeability) and homogeneity of the geological materials, moisture conditions at the time of disposal, background levels, and desirable levels of soil chemical parameters. From an environmental point of view surface spreading is the most desirable disposal option. The best time for surface spreading is during the summer months when temperature (10-30°C) conditions are favorable for microbial activity. Nutrient, pH, oxygen and moisture requirements can be manipulated by the addition of fertilizer, lime, tillage and irrigation, respectively. The wastes could be applied as fluid (slurry) or solid sludge similar to municipal sludges. Fluids could be disposed with industrial or farm equipment such as a tractor and tank wagon, solid sludges with farm spreaders. The depth of incorporation varies with the equipment (10-30 cm) which could be discs, rotivators, rototillers, and ploughs. The use of flotation tires to avoid compaction and structural damage of soils is recommended. The dilution effect is best with the deeper incorporation depth. Microbial activity is highest in A horizons which are about 15 cm thick in Brown Chernozems, 20 cm in Dark Brown Chernozems, 20-30 cm in Black and Dark Gray Chernozems. Luvisols have only a thin litter layer which ideally should be incorporated when wastes are mixed with Ae and B horizon material. Surface sludge application on frozen soil is not recommended due to high run-off potential.

Squeezing of wastes is acceptable provided the solids are also brought to the surface. Use of rippers could enhance infiltration rates and reduce runoff. This could also be done in winter with reduced impact on soil physical properties.

Trenching and burying of wastes are not recommended primarily from a groundwater point of view. However, if surface spreading is not possible due to limiting site conditions, some alternatives have to be sought.

Loudin and McGlothlin (1975) have experimented with soluble silicates and silicate setting agents to solidify mud and cuttings. The aim is to render the mud and cuttings compounds insoluble and as such environmentally safe for burial. Gulf Canada is currently experimenting with solidification of an invert mud and one year's results have been promising (Callow, 1986). No long term studies on solidified buried material have been conducted and there is skepticism as to how long the solidification will last (Becker, 1986). Other alternatives would be: to reduce the waste volume as much as possible, for example by enhanced chemical centrifuging; to haul the waste off-site to a central waste disposal site, a special waste disposal or treatment facility; or disposal in a disposal well.

Another concept of dealing with wastes is utilization rather than disposal. This concept is used for the disposal or better utilization of sewage sludges. As indicated in Section 5, drilling wastes can be beneficial under certain conditions e.g. addition of fine materials to sandy soils, or addition of K to K-deficient soils, provided groundwater contamination is prevented. This concept is partially applied when drilling wastes are surface spread. More research is needed to investigate interaction between muds and soils during surface spreading. Such studies are needed to provide acceptable permissible loadings under varying environmental conditions and to determine the best methods of application and incorporation.

7.5 WASTE MANAGEMENT PLAN

Areas of high drilling density and high volume or centralized sumps, such as Cold Lake, pose a special disposal problem due to accumulation of very large volumes of concentrated wastes. Before exploration of a designated oil or gas field commences the environmental impact of the wastes generated should be assessed. Such environmental impact assessments should consider the following regional issues: soil and vegetation patterns, present and potential land use, proximity to populated areas, watersheds in the area and their uses, groundwater flow patterns, aquifers which are or may become sources of domestic water, depth to water table and depth to bedrock.

Site specific issues are detailed characterization of soils, hydrology, hydrogeology and land use. Groundwater and soils monitoring systems should be installed at longer term waste containment/ disposal sites. Generated waste volumes and concentrations should be projected by the industry. If disposal problems could arise from the use of certain drilling mud systems, alternative drilling mud systems should be considered. If the oil or gas field is located in an environmentally sensitive area, the wastes may have to be disposed elsewhere. A joint effort by the companies involved could make storage, transport and safe disposal of the wastes more economical.

8. RESEARCH NEEDS

Recommended research requirements to reduce environmental impact of drilling waste disposal are grouped as follows:

- organizational - focussing on applying existing knowledge in a better way, and

- technical - focussing on developing new criteria/standards and techniques (to fill information gaps) for waste management. This includes noxious properties, in particular, harmful levels of constituents such as organics and heavy metals.

Clearly, organizational and technical research needs are linked; however, the organizational improvements are perhaps more attractive in the short term because they provide opportunities for quick implementation and immediate environmental protection. Note that the sequence of recommendations for research following does not reflect priority.

Focus on Organization

1. Regional Plans. Develop waste management plans. This should be done on a watershed basis, taking into account past, present and future drilling, types of drilling muds, environmental (physical and biological) conditions, land use, and so forth.

2. Site-specific Plans. Design practical, rapid, reasonably priced but environmentally sound plans for waste management at a site-specific level. Factors to be considered would include soils, groundwater, hydrology, vegetation, land use, drilling muds, etc. The accompanying field manual is a first step in this direction.

3. Fast laboratory results. Develop a "mobile lab" or central regional labs for quick testing of key constituents in sumps, at least for the routine types of analyses. For example, measurement of salinity, pH and a microtox test all done in a day or less. Such lab information combined with a list of mud types used (contents and volumes) and a knowledge of regional and site-specific environmental conditions (arising from points 1 and 2 above) would allow a field officer to make decisions quickly and responsibly. Attention must be given to standardized reporting procedures, kg/m^3, preferably.

4. Update Directives. Expand and integrate various "Directives" to take into account points 1, 2 and 3 above.

5. Environmental Alert. The drilling and mud industries should place greater emphasis on environmental impact of drilling wastes, that is, consider the environmental impact in addition to mud performance in drilling, cost, convenience, etc. Consider certification of formulations based on toxicities to various components of the environment.

6. Data Management. Computerization of records about sump characteristics would allow data assessment and manipulation, for prediction of sump characteristics from sump input data, and for determining environmental impact when the sump content is disposed.

Focus on Technical Understanding

1. Organic Constituents. Solubilities, potential decomposition products and related toxicities of organics in various environments are not well understood. Basic research is needed to investigate the potential effect of organics on soils, vegetation and animals, and potential migration of decomposition products to surface waters or groundwaters.

2. Trace Elements/Heavy Metals. The magnitude of trace elements and heavy metals in sumps is not well documented. Research is needed in this regard to determine the form, concentration ranges, and total levels of various elements in sump fluids and solids.

3. Permissible Loadings. Loadings for various waste constituents on the environment should be established. Research on soils, vegetation and hydrology is needed to establish benchmark levels for beneficial and toxic effects of some elements on plants and animals. Analytical procedures must be calibrated and standardized to assist in making interpretations and recommendations. Tests of key vegetation on various Alberta soils should be performed.

4. Waste Processing Technologies. Technologies for reducing waste volumes and toxicities, such as recycling merit more attention and further development. Also, the mud industry should aim at producing formulations which minimize or eliminate environmental hazards.

5. Surface Solids Disposal. Disposal of solids should be addressed in future research projects, in relation to materials handling as well as to impacts on the environment.

6. Interactions of Constituents. The problems of interactions of different muds (fluids and solids) warrants further research, in terms of both treatment and disposal. Compounds that should not be mixed should be flagged.

7. Sampling, Analysis, and Interpretation Techniques. Develop rapid, cost effective techniques for sampling and analyzing liquids and solids. Calibrate laboratory results against field observations to ensure that environmentally sound interpretations/recommendations are made.

8. Computer Modelling. Considerable information and capabilities in assessing and predicting the environmental behavior of trace elements is embodied in the recently developed geochemical models such as GEOCHEM, MINETEQ, WATEQ, and SOLMENEQ. These are extremely powerful computer models containing codes based on the most recent thermodynamic constants and properties and are being used as tools to evaluate precipitation-dissolution and adsorption-desorption reactions and reactions with organics. In the U.S. they are being used to assess fate of leachates from disposal environments such as fly ash disposal sites and to help select best disposal sites for various waste materials.

   There is a large body of information embodied in computer codes that could be effectively applied to the management and decision making required in considerations of disposal of drilling fluids. What is required in order to capitalize on existing information and technological is detailed information on the chemistry of the waste materials.

9. Survey of Old Sites. A field investigation and sampling of old sump sites, where documentation on mud types and/or sump analysis is available, is recommended. The purpose would be to assess effects on soil physical and chemical properties, on groundwater and on vegetation. This research should not be directed to reclaiming old sites, rather, it should concentrate on the environmental conditions of the sites and the longer term impact of drilling and waste disposal. It is recognized that such an evaluation would be difficult due to lack of background information. Nevertheless, evaluation of even a few sites with documented sump characteristics and known disposal procedures should prove to be extremely informative.

9. REFERENCES

Abouguendia, Z., L. Baschak, R. Godwin, 1985. Study on Potential Environmental Effects of Drilling Wastes on Crops and Soils in Saskatchewan - Phase I. 2 Volumes - Vol. 1, Preliminary Evaluation and Vol. 2, Appendices. Saskatchewan Energy and Mines.

Alberta Environment, 1982. Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands.

American Public Health Association, 1960. Standard Methods for the Examination of Water and Wastewater including Bottom Sediments and Sludges. 11th Ed. New York.

American Public Health Association, 1967. Standard Methods for the Examination of Water and Wastewater. 12th Ed. New York.

Anderson, T.E., 1980. Future use of polymers in drilling fluids. In: Harben, P.W. (Ed.), 1980: Proc. of Minerals and Chemicals in Drilling Muds. pp. 62-67.

Babin, J. and D.D. Trew, 1985. The impact of the proposed Sand River Reservoir on water dissolved oxygen levels in the Beaver and Sand Rivers. Water Quality Control Branch, Alberta Environment, Edmonton. Cold Lake-Beaver River long term water management study: Appendix H.

Baker, J.M., 1970. The effect of oil on plants. In: Environmental Pollution 1:27-44.

Bates, M.H., 1980. Fate and Transport of Heavy Metals. In: Proceed. of the Seminar on Ground Water Quality. July 1980. Univ. of Oklahoma. Norman, Oklahoma. p. 213-229.

Becker, R.F., 1986. Development of Incinerators for Oily Sludges and Cuttings at Remote Sites. Paper presented at the Conference on Petroleum Waste Management " A Western Perspective". C.P.A. and Infotech. Calgary Convention Centre, Alberta. January 22 & 23, 1986.

Becker, R.F., 1985. Chemically Enhanced Centrifuging for Reducing Quantity and Cost of Gel and Saline-Based Drilling Wastes. Paper presented at Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 24, 1985, sponsored by Alberta Energy and Natural Resources.

Benson, L.M., E.K. Porter and P.J. Peterson, 1981. Arsenic accumulation, tolerance and genotypic variation in plants on arsenical mine wastes in S.W. England. J. of Plant Nutrition 3(1-4):655-666.

Benta, G.R., 1980. The use of crystalline salt in drilling, workover, and completion fluids. In: Harben, P.W. (Ed.), 1980: Proceedings of Minerals and Chemicals in Drilling Muds. pp. 85-87.

Bergh, L., 1985. Portable process for stripping solids and filtering drilling wastes. A paper presented at the National Conference on Disposal of Drilling Wastes, Norman, Oklahoma, May 30-31, 1985.

Bernstein, L., 1964. Salt tolerance of plants. U.S.D.A. Inform. Bull. No. 238, 23 pp.

Berry, D.F. and S.A. Boyd, 1985. Reaction rates of phenolic humic constituents and anilines during cross-coupling. Soil Boil. Biochem. 17:631-636.

Bioquest International Inc., 1986. Toxicity testing of oil well sump fluids using the Panagrellus redivivus bioassay and two tests for mutagenesis. Draft Final Report prepared for ERCB, Calgary.

Black, S., D. Graveland, W. Nicholaichuk, D. Smith, R. Tobin and M. Webber, 1984. Manual for land application of treated municipal wastewater and sludge. Environment Canada EPS 6-EP-84-1.

Bost, G., 1985. Hydrologic and environmental effects of drilling mud pits and produced water impoundments. Nation. Conf. on Disp. of Drill. Wastes, Oklahoma.

Buckman, H. and N. Brady, 1969. The nature and properties of soils - seventh edition. Macmillan - London. 653 pp.

Byrd, R., 1985. Recycling drilling wastes. A paper presented at the National Conference on Disposal of Drilling Wastes, Norman, Oklahoma, May 30-31, 1985.

Callow, L., 1986. Gulf Canada Corporation. Personal Communication.

Calloway, M., 1986. Experience in Stabilization of Alberta Oilfield Waste. Paper presented at the Conference on Petroleum Waste Management "A Western Perspective". January 22 and 23, 1986. Calgary Convention Centre. C.P.A. and Info-Tech.

Canadian Petroleum Association, 1984. Waste Disposal Guidelines for the Petroleum Industry.

Canadian Petroleum Association, 1980. Environmental Operating Guidelines for the Alberta Petroleum Industry. Part 1: Environmental Legislation. Part 2: Operating Guidelines.

Canadian Petroleum Association, 1976. Drilling Fluid Additives Datafile. pp. 17-39.

Canter, L.W., et al., 1984. Environmental Implications of Off-Site Drilling Mud Pits in Oklahoma. Report Submitted to Oklahoma Corporation Commission, Oklahoma City, Oklahoma. May 1984.

Canter, L.W., 1985. Drilling waste disposal: environmental problems and issues. In: Proc. of National Conference on Disposal of Drilling Wastes held May 30-31, 1985. U of Oklahoma Environmental and Ground Water Institute. Oklahoma.

Chapman, H.D., 1966. Alkali and saline soils. In: Diagnostic Criteria for Plants and Soils, H. Chapman, (Ed.) University of California, Agric. Exp. St., Riverside, California. p. 510-527.

Charlton, S.E.D., 1986. Water quality among southern Alberta lakes and reservoirs. Pollution Control Division, Alberta Environment, Calgary. Draft Report.

Charlton, S.E.D., D. Hammond and H.R. Hamilton, 1982. Trophic status of Eagle Lake. Pollution Control Division, Alberta Environment, 15 pp., Calgary.

Chilingarian, G.V. and P. Vorabutr, 1981. Drilling and drilling fluids. Amsterdam, Netherlands: Elsevier Scientific. 767 p. 111 (Developments in petroleum science; 11)

Conway, R. and R.D. Ross, 1980. Handbook of industrial waste disposal. Van Norstrand Reinhold Co., N.Y.

Corcoran, D., 1985. Disposal Options for High Chloride Sump Fluids. Gulf - File note 1985-07-06.

Crabtree, A.F., 1985. Drilling Mud and Brine Waste Disposal in Michigan. A paper presented at a Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 23-24, 1985.

Dean, K.C. and R. Havens, 1972. Stabilization of problem mineral wastes. U.S. Dept. of Interior, Bureau of Mines, Salt Lake City Metalurgy Research Centre.

Deeley, G.M. and L.W. Canter, 1985. Chemical speciation of metals in nonstabilized and stabilized drilling muds. A paper presented at the National Conference on Disposal of Drilling Wastes, Norman, Oklahoma, May 30-31, 1985.

Dick, R.I., 1975. Sludge Treatment, Utilization and Disposal (Literature Review). Journal of the Pollution Control Federation 47(6): 1306-1323.

Duke, T.W. and P.R. Parrish, 1976-1984. Results of the Drilling Fluids Research Program Sponsored by the Gulf Breeze Environmental Research Laboratory and Their Application to Hazard Assessment.

Eaton, F.M., 1966. Total salt and water quality appraisal. In: Diagnostic Criteria for Plants and Soils, H. Chapman (Ed.), University of California, Agric. Exp. St., Riverside, California. p. 501-508.

Edgerton Research Laboratory, 1984. A survey of the toxicity and chemical composition of used drilling muds. U.S. Enviro. Prot. Agency. EPA-600/3-84-071.

Edwards, N.T., 1983. Polycyclic Aromatic Hydrocarbons (PAH's) in the Terrestrial Environment - A Review. J. Env. Qual., 12(4):427-441.

Edwards, I., 1985. Salt effects on vegetation. A paper presented at Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 24, 1985, sponsored by Alberta Energy and Natural Resources.

Energy and Natural Resources, 1982. Information Letter 82-5. Potassium-based Drilling Mud Systems.

Energy Resources Conservation Board, 1975. Interim Directive ID-OG 75-2: Sump Fluid Disposal Requirements.

Energy Resources Conservation Board, 1981. Interim Directive ID 81-1: Subsurface Disposal of Drilling Fluids.

Energy Resources Conservation Board, 1982. Oil and Gas Regulations, R-57, Rev. 33:2/82. Care of Well Sites and Battery Sites.

Energy Resources Conservation Board, 1983. A study to determine if sampling technique affects sump fluid analysis. 1983 Summer sump sampling project. Internal Report.

Energy Resources Conservation Board, 1984. Map Designated Oil and Gas Fields and Oil Sand Deposits, Main Pipelines, Refineries and Gas Processing Plants as at 31 December 1984. Alberta, Canada.

Energy Resources Conservation Board, 1985. Determination of Toxicity of Sump Fluids. Interim Report No. 1.

Energy Resources Conservation Board, 1985. A Study of Abandoned Wellsites to assess the impacts of drilling site preparation and drilling sump fluid disposal on agricultural soils in Alberta. Internal Report.

Energy Resources Conservation Board, 1986. Proposed amendments to the oil and gas conservation regulations. Draft Report.

Energy Resources Conservation Board, 1986. Alberta Oil and Gas Industry Annual Statistics. pp. 92-93.

Environment Canada, 1974. Analytical Methods Manual. Water Quality Branch. Ottawa.

Environment Canada, 1980. Standard Procedure for Testing the Acute Lethality of Liquid Effluents. Water Pollution Control Directorate. EPS1-WP-80-1. November 1980.

Environment Canada, 1984. Manual for Land Application of Treated Municipal Wastewater and Sludge. EPS 6-EP-84-1.

Environment Canada, 1985. Naquadat (National Water Quality Data Bank). Dictionary of Parameter Codes. Inland Waters Directorate, Water Quality Branch. Ottawa, Canada.

Environment Council of Alberta, 1982. Environmental standards - a comparison of Canadian standards, standard setting processes and enforcement. Report No. ECA83-SP/1, Environment Council of Alberta, Edmonton.

Environmental Conservation Committee of the Canadian Petroleum Association (Ed.), 1977. Handbook of Environmental Guidelines for Drilling Sump Construction. Edition I.

Falk, M.R. and M.J. Lawrence, 1973. Acute toxicity of petrochemical drilling fluids components and wastes to fish. Ottawa: Canada Fisheries and Marine Service, iv, 108 p. Technical report series, no. CEN/T-73-1.

Farquhar, G.J. and J.F. Sykes, 1982. Control of Leachate organics in soil. Conservation and Recycling 5 (1): 55-68.

Federal Provincial Working Group on Recreational Water Quality, 1983. Guidelines for Canadian recreational water quality. Ministry of National Health and Welfare, Ottawa. ISBN 0-660-11478-X.

Ferrante, J.G., 1981. Fate and effects of whole drilling fluids and fluid components in terrestrial and freshwater ecosystems: a literature review. U.S. Environmental Protection Agency. EPA 600/4-81-031.

Finck, A., 1976. Pflanzenernaehrung in Stichworten. Vlg. F. Hirt. Kiel.

Foght, J., 1985. Some Degradative Capabilities of Soil Microbes. Paper presented at the Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 24, 1985. Sponsored by Alberta Energy and Natural Resources.

Forsgren-Perkins Engineering, 1982. Water Base Drilling Mud Land Spreading and Use As a Site Reclamation and Revegetation Medium - A Study For the American Petroleum Institute, Washington, D.C.

Freeman, B.D. and L.E. Deuel, 1984. Guidelines for Closing Drilling Wastes Fluid Pits in Wetland and Upland Areas. In: Proc. 2nd Industrial Pollution Control/Seventh ETCE Conference, February, 1984. New Orleans, Louisiana.

Glenn, W.M. and D. Orchard (Eds.), 1986. Hazardous Waste Management Handbook. 4th Edition. Corpus Information Services. Don Mills, Ontario.

Goodman, G.T. and M.J. Chadwick (Eds.), 1978. Environmental Management of Mineral Wastes. Proc. of the NATO Advanced Study Institute Symposium on Waste Disposal and the Renewal and Management of Degraded Environments. Britain and West Germany. July 13-28, 1973. Sijthoff a. Noordhoff Publ. 10, The Netherlands. 367 pp.

Graveland, D.M., 1979. Utilization of sludges as plant nutrient resources in the Oldman River basin. Proceedings Alberta Soil Science Workshop, Lethbridge, 1979. p. 169-190.

Gray, G.R., and H.C.H. Darley, 1980. Composition and Properties of Oil Well Drilling Fluids. Gulf Publ. Company. Houston.

Harben, P.W., 1980. Proceedings of Minerals and Chemicals in Drilling Muds.

Health and Welfare Canada, 1978. Guidelines for Canadian drinking water quality. Federal-Provincial working group on drinking water quality. Ministry of National Health and Welfare. ISBN 0-660-10429-6.

Henderson, C. and C.M. Tarzwell, 1957. Bio-assays for control of industrial effluents. Sew. Ind. Wastes 29:1002-1017.

Henderson, G., 1982. Analysis of Hydraulic and Environmental Effects of Drilling Mud Pits and Produced Water Impoundments. Dames and Moore, Houston, Texas. Report avail. from A.P.I., Dallas, Texas.

Hill, J.R.C., 1983. Toxic tolerance in populations of plants selected to stabilize mine wastes in Zimbabwe. Reclam. and Reveg. Res. 2(3):217-225.

Hornick, S.B., 1982. Organic wastes for revegetating marginal lands. Biocycle 23(4):42-43.

Hrudy, S.E., 1983. Special Waste Residue Management for Alberta. Dept. of Civil Engineering. U of A for Research Management Division. Alberta Environment, RMD Report 84/27.

Inland Waters Directorate, 1979. Guidelines for surface water quality. Vol. 1, Inorganic substances. Environment Canada, Ottawa.

Johnson, M.S. and A.D. Bradshaw, 1977. Prevention of heavy metal pollution from mine wastes by vegetative stabilization. Transactions of the Institute of Mining and Metallurgy, London 86(A):A47-A55.

Johnson, W.E., 1961. Wind and water erosion in western Canada. Agricultural Institute Review: 12-15.

JRB Associates, Inc., 1982. Handbook for remedial action at waste disposal sites. Prepared by JRB Associates, Inc., McLean, Virginia. U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio. Report No. EPA-625/6-82-006.

Kaiser, K.L.E., 1984. Organic contaminants in the environment: research progress and needs. Environment International 10:241-250.

Keen, P.W. and J.G. Sampson, 1983. The Sand/Clay Mix Technique: A method of clay disposal and reclamation options. In: Proc of the Symposium on Reclamation and the Phosphate Industry. Robertson, D.J. (Ed.). Clearwater Beach, Florida. p. 59-84.

Kerschueren, K., 1983. Handbook of environmental data on organic chemicals. 2nd ed. Van Norstrand Reinhold: N.Y.

Khalid, R.A., 1977. Transformation of heavy metals and plant nutrients in dredged sediments as affected by oxidation reduction potential and pH. U.S. Army Engineering Waterways Experiment Station. Vidasburg, Miss.

Land, B., 1974. The toxicity of drilling fluid components to aquatic biological systems: a literature review. Winnipeg: Canada Fisheries and Marine Service, 1974. 33 p. Canada Fisheries and Marine Service, Technical Report 487.

Lawrence, M. and E. Scherer, 1974. Behavioral responses of whitefish and rainbow trout to drilling fluids. Winnipeg Canada Fisheries and Marine Service. 47 p. Technical Report 502.

Leisinger, T., A.M. Cook, R. Hutter and J. Nuesch (Eds.), 1981. Microbial Degradation of Xenobiotics and Recalcitrant Compounds. Academic Press. London.

Lenzini, D., 1980. BLM testing of drilling muds on Wyoming soils. Western Oil Reporter 37(7):120-121.

Lepp, N.W., 1981. Effect of heavy metal pollution on plants. Applied Science Publishers, London.

Lloyd, D.A., 1985. Drilling waste disposal in Alberta. A paper presented at the National Conference on Disposal of Drilling Wastes, Norman, Oklahoma, May 30-31, 1985.

Louden, L.R. and R.E. McGlothlin, 1975. Waste Water Base Drilling Fluid Disposal. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. U.S. Environmental Protection Agency. EPA-560/1-75-004.

LRRC and North Dakota State University, 1985. Conference on Identifying and Remedying Effects of Oilfield Brine and Drilling Fluids on Soils and Groundwater, April 10, 1985.

Mackay, D.M., P.V. Roberts, J.A. Cherry, 1985. Transport of organic contaminants in groundwater. Environ. Sci. Technol., 19: 384-392.

McDermott, J., 1973. Drilling Mud and Fluid Additives. Noyes Data Corp. Park Ridge, New Jersey, Landon, England. Chemical Technology Review No. 20.

McKeague, J.A. (Ed.), 1978. Manual on soil sampling and methods of analysis. 2nd Edition. Prepared by the Subcommittee on Methods of Analysis of the Canada Soil Survey Committe. Canadian Society of Soil Science. Ottawa. 212 p.

McNeely, R.N., V.P. Neimanis and L. Dwyer, 1979. Water quality sourcebook. A guide to water quality parameters. Inland Waters Directorate, Environment Canada. 89 pp.

Mead, D.A., 1985. Environmental, Geological and Operations Considerations when using Saline Drilling Fluids - Shell Canada's Experience.

Miller, R. and S. Honarvar, 1975. Effect of drilling fluid components and mixtures on plants and soils. In Environmental Aspects of Chemical Use in Well-Drilling Operations. U.S. Environmental Protection Agency EPA-560/1-75-004.

Miller, R., S. Honarvar and B. Hunsaker, 1980. Effect of drilling fluids on soils and plants: I. Individual fluid components. J. Environ. Qual. 9(4):547-552.

Miller, R. and P. Pesaran, 1980. Effects of drilling fluids on soils and plants: II. Complete drilling fluid mixtures. J. Environ. Qual. 9(4):552-556.

Moody and Associates, Inc., 1983. Oil and Gas Well Pollution Abatement Project, Parts A-D. Meadville, Pennsylvania.

Moseley, H.R., Jr., 1980. Drilling Fluids and Cuttings Disposal. Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp. 43-52. Lake Buena Vista. Florida. January 21-24, 1980.

Murphy, E.C. and A. Kehew, 1984. The effect of oil and gas well drilling fluids on shallow groundwater in western North Dakota. Report of Investigation No. 82. N. Dak. Geol. Surv., Grand Forks, North Dakota.

Musser, D., 1985. Physical/chemical stabilization of drilling muds. A paper presented at the National Conference on Disposal of Drilling Wastes, Norman, Oklahoma, May 30-31, 1985.

NL Baroid, 1983. Drilling Mud Handbook. Copyright NL Industries Inc.

Nelson, D.W., S. Liu and L.E. Sommers, 1980. Plant uptake of toxic metals present in drilling fluids. Symposium-Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, Florida. Jan. 21-24, 1980.

Nelson, D.W., S. Liu and L.E. Sommers, 1984. Extractability and plant uptake of trace elements from drilling fluids. J. Environ. Qual. 13(4):562-566.

Nesbitt, L.E. and J.A. Sanders, Amoco Production Co., 1981. Drilling Fluid Disposal. Paper presented at the 56th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineerings. San Antonio, Texas. October 5-7, 1981.

Neyrfor Canada Ltd., 1986 Personal Communication.

Ogden, P.H. (Ed.), 1983. Chemicals in the Oil Industry. Special Publ. No. 45. Printed in Great Britain by H. King Ltd., Dorset, Great Britain.

Oilweek, 36, No. 51, January 20, 1996. Drilling at a Glance.

Pace, 1983. Groundwater and Petroleum Hydrocarbons - Protection, Detection, Restoration. Proceedings of a Seminar. Toronto, Ontario June 26-28.

Page, A.L., R.H. Miller and D.R. Keeney (Eds.), 1982. Methods of Soil Analysis. Part 2. Chemical and Micro-biological Properties. 2nd Ed. Agronomy No. 9. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin. 1159 p.

Palmer, C.J., 1985. Drilling Wastes as a Soils Component. Paper presented at the Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 24, 1985. Sponsored by Alberta Energy and Natural Resources.

Pan T.I. Ltd., 1981. The Chemistry and Physiology of Sumps. March/81.

Peake, E., D. Connery, D. Holowachuk, W. Weibe, 1985. Land Treatment for the Disposal of Oily Waste Sludges. C.P.A., October 1985.

Pedology Consultants, 1985. Identification and Mapping Water Erosion, Wind Erosion, Soil Salinity. Report by Pedology Consultants for Alberta Agriculture.

Perricone, Ch., 1980. Major Drilling Fluid Additives - 1979. Symposium - Research on Environmental Fate and Effect of Drilling Fluids and Cuttings. pp. 15-29. Lake Buena Vista, Florida. January 21-24, 1980.

Pesaran, P., 1977. Effects of drilling fluids on soils and plants. A paper presented at 69th Ann. Meeting Amer. Soc. Agron./Crop Sci. Soc. Amer./Soil Sci. Soc. Amer., Los Angeles, California, November 13-18, 1977.

Powers, W.L., G.W. Wallingford and L.S. Murphy, 1975. Formulas for applying organic wastes to land. J. Soil and Water Conservation, 30(6):286-289.

Public Lands Division Handout 0799G: Guidelines for Sump Fluid Disposal on Crown Land. White and Yellow areas.

Ram, N. and M. Verloo, 1985. Effects of various organic materials on the mobility of heavy metals in soil. Environmental Pollution (Series B): 241-248.

Reed, S.C. and R.W. Crites, 1984. Handbook of Land Treatment Systems for Industrial and Municipal Wastes.

Reports of industry/government research on pollution from drilling wastes. Edm. Alta. Environmental Protection Service, Jan. 1976. 13v: ill.

Reynoldson, T.B., 1983. North Saskatchewan River Water Quality 1970-1981. Alberta Environment, Pollution Control Division, 34 pp., Edmonton.

Richards, L.A. (Ed.), 1954. Diagnosis and Improvement of Saline and Alkali Soils. United States Saline Laboratory Staff. United States Department of Agriculture. Handbook 60. Washington, D.C. 160 p.

Ridosh, M.H., 1981. A case study of land application of oilfield wastes. Applied Research and Practice on Municipal and Industrial Waste - 4th Conference, Madison, Wisconsin, September 30, 1981.

Robertson, J.A., 1983. Introductory Soil Science. Laboratory Manual. Dept. Soil Science, U of Alberta, Edmonton.

Robichaux, T.J., 1975. Bactericides used in drilling and completion operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. U.S. Environmental Protection Agency EPA-560/1-75-004. p. 183-191.

Routson, R.C., R.E. Wildung and R.M. Bean, 1979. A review of the environmental impacts of ground disposal of oil shale wastes. J. of Env. Quality 8(1):14-19.

Samoiloff, M.R., 1980. Action of Chemical and Physical Agents on Free-Living Nematodes. In: Nematodes as Biological Models. Academic Press Inc. pp. 81-98.

Savage, G.M., L.F. Diaz, C.L. Golueke, 1985. Biological treatment of organic toxic wastes. Biocycle 26(7): 30-33.

Scafe, D.W., 1975. Alberta Bentonites. Economic Geology Report No. 2. Edmonton, Alberta.

Scharer, J.M. and B. Ibbotson, 1982. Bacterial oxidation of inorganic compounds in mining wastes. Conservation and Recycling 5(1):47-53.

Scheffer, F. and P. Schachtschabel, 1979. Lehrbuch der Bodenkunde. Vlg. F. Enke. Stuttgart. West Germany.

Schonekess, P., and D. Hammond, 1979. Crowsnest River water quality study. Water Quality Control Branch, Alberta Environment, Calgary. 45 pp.

Shaw, D., Chief Chemist, ERCB Research Lab. Pers. Comm. (1985 and 1986).

Shaw, D., 1985. Toxicity Testing and Laboratory Procedures for Analyzing and Evaluating Drilling Fluids. Paper presented at the Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 24, 1985. Sponsored by Alberta Energy and Natural Resources.

Shaw, D.R., 1984. Disposal of Invert Emulsion Muds. Internal Paper.

Shaw, D.R., 1975. The toxicity of drilling fluids, their testing and disposal. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. U.S. Environmental Protection Agency EPA-560/1-75-004.

Shell Canada Resources Ltd., 1984. 1984 Drilling Fluid Summary.

Shuckrow, A.J., A.P. Pajak, and C.J. Touhill, 1982. Hazardous Waste Leachate Management Manual. Noyes Data Corp., Park Ridge, New Jersey, U.S.A. Pollution Technology Review No. 92.

Smith, D.W. and T.D.W. James, 1979. Sump Studies III - Biological Changes in Permafrost Terrain Adjacent to High Arctic Oil and Gas Wellsites. Environmental Studies No. 16. Dept. Indian and Northern Affairs.

Specken, G.A., 1975. Treatment and disposal of waste fluids from onshore drilling sites. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. Conference Proceedings EPA-560/1-75-004.

Specken, G.A., 1985. Sump sampling procedures and problems to be aware of. Sump treatment. A paper presented at a Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 23-24, 1985.

Spectra Water Processes Ltd., 1985. Laboratory Treatment of Sump Fluid Samples. Information letter regarding treatments to ERCB Chemical Research Lab.

Standards and Approvals Division, 1977. Alberta surface water quality objectives. Water Quality Branch, Alberta Environment, Edmonton. 17 pp.

Stanley/SLN Consulting, 1978. Oldman River Basin. Irrigation Studies. Efficiencies, Seepage and Salinity. Expansion Priorities. April 1978.

Strosher, M.T., W.E. Younkin and D.L. Johnson, 1980. Environmental assessment of the terrestrial disposal of waste drilling muds in Alberta: Chemistry of sump fluids and effects on vegetation and soils. Prepared for the Canadian Petroleum Association, Calgary, Alberta.

Strosher, M.T., 1984. A Comparison of Biological Testing Methods in Association with Chemical Analyses to Evaluate Toxicity of Waste Drilling Fluids in Alberta. Kananaskis Centre for Environmental Research, University of Calgary. Can. Petr. Assoc., Jan. 1984. 2 v.

Torrey, S. (Ed.), 1979. Sludge Disposal by Landspreading Techniques. Noyes Data Corporation. Park Ridge, New Jersey, U.S.A.

Tramier, B., 1982. Land impact of drilling fluids reserve pits in southwestern France. Proceed. 4th Ann. Meet. Soc. Pet. Indust. Biol.

Trew, D.D., E.I. Yonge and R.P. Kaminski, 1983. Lake trophic assessment. Appendix of Cold Lake-Beaver River Water Management Study. Volume 8; Water Quality, Planning Division, Alberta Environment, Edmonton.

Tucker, B., 1985. Soil application of drilling wastes. A paper presented at the National Conference on Disposal of Drilling Wastes, Norman, Oklahoma, May 30-31, 1985.

U.S. Salinity Laboratory, 1954. Diagnosis and improvement of saline and alkali soils. U.S. D.A. Handbook 60, 160 pp.

U.S.D.A., 1972. Guide for Interpreting Engineering Uses of Soils.

Van den Berg, L., 1982. Anaerobic Digestion of Wastes. Conservation and Recycling 5(1):5-14.

Van Loon, J.C., 1974. Analysis of heavy metals in sewage sludge and liquids associated with sludges. Presented at Canada/Ontario Sludge Handling and Disposal Seminar, Toronto, September 18-19, 1974. 17 pp.

Walker, R.E., 1985. Saskatchewan government research into environmental aspects of heavy oil development: an overview. A paper presented at the Workshop on Research and Development Related to Oil Sands, Heavy Oil and the Environment. Calgary, Alberta, April 25, 1985.

Water Quality Branch. NHRI. July, 1979.

Western Fertilizer Handbook, 1980. Sixth Edition. California Fertilizer Association.

Whitby, L., A. MacLean, M. Schnitzer and J.D. Gaynor, 1977. Sources, storage and transport of heavy metals in agricultural watersheds. International Reference Group on Great Lakes Pollution from Land Use Activities, Inter. Joint Commission, Windsor, Ontario. 142 pp.

Whittaker, H., 1986. Membrane Technology in the Oil Patch. Paper presented at the Conference on Petroleum Waste Management "A Western Perspective". January 22 and 23, 1986. Calgary Convention Centre. C.P.A. and Info-Tech.

Wilkerson, D.L., 1984. Survey of Drilling Mud Use and Disposal. Alaska Dept. of Environmental Conservation. Environmental Quality Management.

Weleschuk, I., 1986. Section Head, Land Management, Environment Protection Department. ERCB Calgary. Personal Communication.

World Oil, 1984. World Oil's Guide to Drilling, Completion and Workover Fluids. Gulf Publ. Co., Houston, Texas.

Yonkin, W.E. and D.L. Johnson, 1980. The impact of waste drilling fluids on soils and vegetation in Alberta. Symposium - Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. pp. 48-113. Lake Buena Vista, Florida. January 21-24, 1980.

Zitko, V., 1975. Toxicity and environmental properties of chemicals used in well-drilling operations. In: Environmental Aspects of Chemical Use in Well-Drilling Operations. U.S. Environmental Protection Agency. EPA-560/1-75-004. p. 311-326.

APPENDIX A

CHARACTERISTICS OF DRILLING WASTES

Appendix Table A1. Fresh Water Muds Used in Alberta (after Ziedler, 1985).

MUD TYPE	APPLICATION	AREA	PRIME CONSTITUENTS	MAJOR ADDITIVES	
				Name	Concentration
Native Mud	Shallow surface holes Upper portion of main hole in shallow wells	SE Alberta E of 4th M	Water Solids from drilled formation	Sodium Acid Pyrophosphate	0.05 kg/m^3
Clear Water Drilling Fluid	1500-2200 m depth	Common in Plains and Foothills	Water	Lime ($CaCO_3$) Calcium Chloride ($CaCl_2$) Flocculating polymer (usually polyacrylamide)	pH 10-11 100-200 mg/l C 800-1500 mg/l (very low (mostl adsorbed onto solids)
Inhibitive Water Drilling Fluid	to prolong clear water drilling program to reduce swelling of water sensitive shales and shaly sands		Water	same as Clear Water Drilling Fluid but Potassium Chloride (KCl) instead of $CaCl_2$	10,000-20,000 mg/l
Bentonite (Gel) Viscosified Mud	Base of many fresh water mud systems usable anywhere if contaminants[1] absent and temperature and pressure requirements not excessive [1] high drilled solid concentration anhydrite NaCl or $CaCl_2$ H_2S - gas	Anywhere if conditions right	Water Bentonite (Sodium Montmorillonite or "Gel" 35-70 kg/m^3	Caustic Soda (NaOH) Carboxymethyl-cellulose (CMC)	pH 9-10 1-3 kg/m^3
Extended Bentonite Mud (Extended "Gel" System)	Where higher viscosity needed	anywhere	as Bentonite Viscosified Mud	as Bentonite Viscosified Mud plus Polymer	1:200-300 weight/weight ratio with bentonite
Bentonite-Water Viscosifying Polymer Mud	Where low solids and higher viscosity needed	anywhere	Water Bentonite 20-40	as Bentonite Viscosified Mud plus Polymer, e.g. xanthan gum guar gum CMC polanionic cellulose hydroxyethyl cellulose polyacrylamide Polyacrylate	1-5 kg/m^3

Appendix Table A2. Saline Water Muds in Alberta (After Ziedler, 1985).

MUD TYPE	APPLICATION	AREA	PRIME CONSTITUENTS	MAJOR ADDITIVES	
				Name	Concentration
Inhibitive Mud	where water sensitive formations exposed for prolonged periods of time (shale inhibition) where water sensitive producing formations	Foothills (deep wells) occasionally Plains	Water Potassium Chloride (KCl 20,000-40,000 mg/l) or	Polymer such as polyanionic cellulose, polyacrylate, xanthan gum	1-3 kg/m^3
			Potassium Sulphate (K_2SO_4 10,000-30,000 mg/l) or	(for enhanced inhibition partially hydrolyzed polyacrylamide)	0.5-1.5 kg/m^3
			Diammonium Sulphate ($(NH_4)_2SO_4$ 10,000-20,000 mg/l)	Caustic Soda ($NaOH$) for KCl and K_2SO_4	pH 9.5-10.5
			Prehydrated Bentonite 15-35 kg/m^3	Ammonium bisulphite NH_4HSO_3 (oxygen scavenger) or Catalyzed Sodium Sulphite Na_2SO_3	200-300 mg/l sulphite
Saturated Mud	For drilling through rock salt, prairie evaporites or where salt water flows common (mixed salts of sodium, calcium and magnesium chloride)	Area of Prairie Evaporites (see Figure _) e.g. Red Water Field, SE of Red Deer	Freshwater or Brinewater Sodium Chloride ($NaCl$ to reach saturated conditions)	Prehydrate Bentonite or Attapulgite or Polymer (i.e. xanthan gum) or Polyanionic Cellulose	pH approx. 7
				Starch	
				Paraformaldehyde or other biocide	0.3-0.7 kg/m^3

Appendix Table A3. Data on Invert Emulsion Muds (after Canadian Petroleum, 1976; NL Baroid, 1983; World Oil, 1984; Ziedler, 1986).

MUD TYPE	APPLICATION	AREA	PRIME CONSTITUENTS	AMOUNT
Invert Emulsion Mud Water is dispersed in oil up to 50% by volume	high temperatures high pressures shale stabilization	Foothills e.g. Grande Prairie SW of Sundre	Diesel Oil	- major volume
			Water	- up to 50% of volume
			Emulsifier	- depending on temperature 30-120
			Lime	- 6-40 kg/m^3
			Barite	- depending on density 2-93 mg/kg
			Calcium Chloride	- approx. 300,000 mg/kg
			Organophilic clay (amine treated clay)	- 3-14 kg/m^3

Appendix Table A4. Common Mud Additives in Alberta (after Ziedler, 1985 and Canadian Petroleum, 1976).

ADDITIVE GROUP	CHEMICAL	FUNCTION
Calcium, Carbonate, Bicarbonate, pH Control	Sodium Hydroxide (NaOH)	to raise, maintain pH to reduce HCO_3, CO_3
	Potassium Hydroxide (KOH)	pH control in KCl muds
	Calcium Hydroxide ($Ca(OH)_2$)	to reduce pH to reduce CO_3
	Sodium Bicarbonate ($NaHCO_3$)	to reduce pH to reduce calcium conentration
	Soda Ash (Na_2CO_3)	to reduce carboantes
Bactericides	Paraformaldehyde	bactericide when starch is used in saturated salt water mud sometimes when xanthan gum used in water viscosifying polymer mud
Corrosion Inhibitor and Scavenger	Ammonium bisulphite, catalyzed sodium sulphite	oxygen scavenger primarily KCl muds
	Blended water soluble organic phosphates	to control scale in high calcium, high pH, high carbonate environment
	Ferro ferric oxide, Zinc compounds such as Zinc carbonate and related Zinc	Scavengers of H_2S sour gas areas
	Film forming amines	Inhibition of H_2S
Defoamers	Aluminum stearate Various alcohols Sulfonated oils	- to reduce foam resulting from air entrapment into mud
Lubricants	diesel or crude oil (3-12% by volume), graphite, glass beads or walnut hills (3-6 kg/m^3	- to reduce friction in crooked holes (foothills) or directional holes (foothills, heavy oil recovery areas, occasionally on plains e.g. when drilling under a lake)
	diesel oil containing 0.05-0.1% by volume of various organic surface-active agents and sulfonated oils	- stuck pipe - after use, fluid passed directly to sump or mixed into entire mud system
Shale Control Inhibitors (apart from inorganic salts, e.g. KCl)	Pure gilsonite; blown asphalt; sulfonated asphalt; partially hydrolized polyacrylanides	- may be incorporated into any water based mud

Appendix Table A4. Common Mud Additives in Alberta (after Ziedler, 1985 and Canadian Petroleum, 1976) (Continued).

ADDITIVE GROUP	CHEMICAL	FUNCTION
Thinners (Dispersing Agents or Dispersants or Deflocculants)	Phosphates, e.g. Sodium acid pyrophosphate, Sodium hexametaphosphate, Sodium tetraphosphate 0.5 kg/m^3	- powerful dispersant - only if temperature <80°C - acidic nature, addition of NaOH - adsorbed to surface of solids, neutralizes charges - not effective at high salt concentrations
	Tannins 6-25 kg/m^3 (15 kg/m^3 common)	- acidic nature - addition of NaOH - best in high pH muds - not effective in high salt concentrations or high calcium environments
	Lignite 6-25 kg/m^3 (15 kg/m^3 common)	- strong dispersant - best in low pH, low calcium and salt concentration
	Lignosulfonates (metallic sulfonate salts) e.g. Chrome Lignosulfonate, Ferrochrome Lignosulfonate 6-25 kg/m^3 (15 kg/m^3 common)	- besides thinning effect it reduces fluid loss and creates inhibitive environment - needs pH>9 - effective in high Ca, salt environment, at >120°C
Weighting Materials	Barite ($BaSO_4$) - inert in pure form - high specific gravity	- for abnormally high formation pressures, high regional or local stress fields
Emulsifiers	Lignite Ca salts of organic acids Oil soluble surfactant	to create a heterogeneous mixture of two liquids, e.g. oil and water
Lost Circulation Materials	Fibrous and Flake Flax Fibre Sawdust Nutshells Mica Synthic Polymer Diatomaceous earth	for plugging zones in the formation where fluid loss occurs

Appendix Table A5. Results from Sump Fluid Analyses Conducted at the ERCB Lab between August and December, 1985.

Location	Mud System (guessed)	Volume (bbl)	Toxicity 96 hr Trout Test	Cl mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	HCO3 mg/l	CO3 mg/l	Na mg/l	K mg/l	Ca+Mg mg/l	TDS_{det}[1] at 105°C	TDS_{calc}[2]	pH
SOUTH CENTRAL PLAINS															
23-24-W4	Salt Water not treated		highly toxic	94	6801			387	82	3120	15	93	10,450	10,592	10.1
	treated		non-toxic	99	7638			994		2980	18	629	12,370	12,358	6.7
CENTRAL PLAINS															
19-28-W4	Fresh Water composite sump oily, dirty, yellow, hydrocarbon odor		non-toxic	124	939	51		491		580	15	115	1,960	2,315	7.9
39-23-W4	Fresh $Water_T$3 thick gray muddy, hydrocarbon odor		highly toxic	50	182	23		428	204	490	12	15	1,270	1,404	10.0
35-5-W5	Fresh Water		non-toxic	679	508			463		570	94	247	2,750	2,562	7.2
36-13-W4	Salt Water		non-toxic	6700	1			476	109	5100	21	156	12,120	12,562	8.0
NE PLAINS															
55-6-W4	Unknown muddy, thick, grey, rainbow effect, hydrocarbon odor		highly toxic	440	1155			159	136	780	18	55	2,400	2,743	9.0
61-4-W4	Unknown extremely thick dark gray mud		highly toxic also at 1:1 dilution	388	1548			28	598	312	940	363	1,050	4,177	11.1
NW PLAINS															
53-13-W5	Fresh Water		non-toxic	1414	152			149		810	21	269	3,250	2,815	6.6
55-27-W5	Fresh Water - Main $Sump_T$		highly toxic	65	657			327		360	12	94	1,400	1,515	7.4
	- Sump $"A"_T$		min. toxic	55	614			327		360	11	94	1,380	1,461	7.2

Location	Mud System (guessed)	Volume (bbl)	Toxicity 96 hr Trout Test	Cl mg/1	S04 mg/1	Po4 mg/1	No3 mg/1	HC03 mg/1	C03 mg/1	Na mg/1	K mg/1	Ca+Mg mg/1	TDS_{det}[1] at 105°C	TDS_{calc}[2]	pH
NW PLAINS															
71-13-W6	Unknown reddish brown, oily, diesel on surface	4,700	highly toxic	2207	54			511	27	380	1780	194	5,950	5,153	9.1
71-6-W6	Unknown oily sludge in corner; hydrocarbon odor; clear fluid, dark gray		highly toxic	1568	143			173	204	1230	17	128	3,300	3,463	8.3
64-6-W4	Salt Water yellow, cloudy		non-toxic at 1:6 dilution	12257	518				788	8500	40	231	22,650	22,334	11.9
62-11-W6	Unknown		highly toxic non-toxic at 1:1 dilution	2670	170			3		196	27	1254	5,200	4,320	4.7
59-2-W5	Salt Water		non-toxic at 1:2 dilution	5388	148			172		2600	830	520	11,060	9,209	6.9
72-11-W6	Fresh Water	6,000	highly toxic	180	101			35	408	332	13	9	1,080	1,078	10.2
54-23-W5	Unknown	32,000	highly toxic	71	825			387	122	540	6	34	2,120	1,985	8.9
46-5-W5	Salt Water murky, orange brown, with sediment, sewage odor		non-toxic	5190	72		15	150		830	2400	1281	10,580	9,937	6.6
79-8-W6	Unknown	5,000	highly toxic	124	922			331		440	12	174	2,090	2,003	7.3
75-10-W6	Unknown	12,000	highly toxic	32	1675			262	720	1260	10		3,960	3,959	10.2
SOUTHERN FOOTHILLS AND MOUNTAINS															
4-1-W5	Unknown hydrocarbon odor		highly toxic	7	316	40		111	612	530	24	4	1,290	1,644	10.4
5-1-W5	Fresh Water diesel fuel in it		highly toxic	422	92			152		166	29	146	1,680	1,007	7.6

Location	Mud System (guessed)	Volume (bbl)	Toxicity 96 hr Trout Test	Cl mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	HCO3 mg/l	CO3 mg/l	Na mg/l	K mg/l	Ca+Mg mg/l	TDS_{det}[1] at 105°C	TDS_{calc}[2]	pH
CENTRAL FOOTHILLS AND MOUNTAINS															
54-1-W6	Fresh Water Sump A_T	9,000	non-toxic	96	2410			269		820	13	296	2,650	3,904	5.2
	Sump B_T	20,000	non-toxic	82	648			663		400	8	72	1,420	1,873	7.1
	Sump C_T		non-toxic	92	747			621		480	8	112	2,110	2,060	7.3
	Sump D_T		toxic	10	34			491		35	2	144	530	716	7.6
52-27-W5	Fresh $Water_T$		highly toxic	53	633			275		307	10	70	1,240	1,350	7.0
57-27-W5	Fresh Water dark brown, murky, hydrocarbon odor	500,000	highly toxic	42	224			393		272	10	32	1,450	973	8.2
45-12-W5	Fresh Water cloudy, slight yellow, sausage odor		toxic	703	766			166		490	25	402	2,610	2,552	6.8
45-7-W5	Fresh Water		min. toxic	508	298			359		590	5	43	1,670	1,624	8.0
42-8-W5	Fresh Water	9,000	highly toxic	619	208			214	82	560	7	7	1,560	1,697	9.6
45-12-W5	Fresh $Water_T$	16,000	highly toxic	778	669			207		480	28	304	3,700	2,466	6.9
47-16-W5	Salt $Water_T$	30,000	toxic as is non-toxic at 1:1 dilution	2307	71			108		129	63	1150	4,950	3,828	6.9
42-8-W5	Invert Mud H_2S odor, murky brown		highly toxic	259	154			338		360	21	67	1,170	1,199	7.1
62-23-W5	Unknown		non-toxic	2569	1026			207	82	1550	22	573	6,310	6,029	8.0
35-8-W5	KCl dilute		min. toxic at 1:2 dilution	4290	297			207	136	800	3800	28	12,050		9.4

Location	Mud System (guessed)	Volume (bbl)	Toxicity 96 hr Trout Test	Cl mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	HCO3 mg/l	CO3 mg/l	Na mg/l	K mg/l	Ca+Mg mg/l	TDS$_{det}$^{1} at 105°C	TDS$_{calc}$^{2}	pH
NW PLAINS															
49-8-W5	Fresh Water$_T$		non-toxic	831	50			104		610	8	224	2,370	1,791	7.1
61-15-W5	Fresh Water$_T$		toxic	276	922			409		690	9	76	2,300	2,382	7.3
87-1-W6	Fresh Water$_T$	4,900	non-toxic	323	1343			297	54	740	9	198	3,060	2,964	8.0
68-15-W5	Fresh Water$_T$		non-toxic	87	73	183		148		94	5	60	1,520	65	6.8
45-7-W5	Fresh Water		non-toxic	887	51			138		259	280	225	2,310	1,840	7.5
77-25-W5	Fresh Water putric odor		highly toxic	150	1463			387		940	17	151	3,060	3,108	7.5
48-7-W5	Fresh Water cloudy, slightly yellow, yellow floc material hydrocarbon odor		non-toxic	907	148		68	110		510	12	209	2,200	1,964	7.1
65-21-W5	Fresh Water murky dark brown, white sediment		non-toxic	67	185			186		152	3	45	490	638	7.6
51-3-W5	Fresh Water		non-toxic	115	547			241.6	36	430	5	71	1,360	1,326	8.6
38-4-W5	Fresh Water murky brown		toxic	367	1033			242	313	900	9	52	2,920	2,796	9.1
51-8-W5	Fresh Water		non-toxic	411	129			276		420	6	43	1,110	1,147	8.0
53-13-W5	Fresh Water		toxic	232	70		some	173	41	280	4	54	810	854	8.4
59-2-W5	Salt Water		non-toxic if diluted at 1:3	8445	126		22	138		4020	1070	782	14,860	14,603	7.7
73-6-W6	Unknown brown muddy fluid		toxic	380	1105			476	82	920	11	24	2,390	2,998	7.9
56-15-W5	Unknown	3,000	highly toxic	600	672			55		440	30	148	1,950	1,945	6.3
69-6-W5	Unknown		toxic	866	185			69	163	750	15	40	1,960	2,088	11.1

Location	Mud System (guessed)	Volume (bbl)	toxicity 96 hr Trout Test	Cl mg/1	S04 mg/1	P04 mg/1	N03 mg/1	HC03 mg/1	C03 mg/1	Na mg/1	K mg/1	Ca+Mg mg/1	TDS_{det}[1] at 105°C	TDS_{calc}[2]	pH
NORTHERN FOOTHILLS AND MOUNTAINS															
79-10-W6	Fresh Water top of sump		non-toxic	34	731			596	88	550	20	78	3,090	2,097	10.0
	lower portion		toxic	78	2290			581	476	1600	19	155	4,940	5,199	10.5
72-11-W6	Fresh Water		highly toxic	233	133			60	322	390	11	7	1,340	1,156	9.7
82-12-W6	Fresh Water cloudy, yellow, oily, hydrocarbon odor		non-toxic	460	1035			152		650	11	157	2,360	2,389	7.0

[1] TDS_{det} : Total dissolved solids determined at 105°C

[2] TDS_{calc} : Total dissolved solids calculated

[3] T : Treated

Non-toxic:	3 Fish alive greater than or equal to 96 hours
Min. toxic:	Less than 3 Fish alive at greater than 96 hours
Toxic:	Less than or equal to 3 Fish dead at less than or equal to 96 hours
Highly toxic:	3 Fish dead at less than 20 hours

Appendix Table A6. Analytical Results of a KCl Sump, a Fresh Water Gel Sump and a NaCl Sump.

Location	Cl Sump Type*	Cl mg/l	SO4 mg/l	HCO3 mg/l	CO3 mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	SAR mg/l	EC mS/cm	Sat%	pH	ESP	Gypsum T/ha
E23, W25-85-19-W4 NW Plains	KCl-Polymer - Solids	925	2,152	87.8	30	851	41.4	838	5.8	8	5.9	64	10.4	14.6	2.2
	- Liquids	690	616	219	72	690	24	180					9.0		
LSD 4-5-65-4-W4 NE Plains	Fresh Water Gel - Solids	103	999	176	96	858	10.6	54.3	0.5	32	4.2	110	11.5	43.7	15.7
	- Liquids	135	111	128	144	270	3	162					10.0		
LSD 14,15-10-65-4-W4 NE Plains	NaCl - Solids	67,361	5,523	146	30	43,681	133	1,494	4.1	311	117	63	10.3	88.1	233
	- Liquids	80,092	2,057		467	55,000	179	221					11.9		

Location	Sump Type*	Oil %	Carbon %	Available N kg/ha	Available P kg/ha	Available K kg/ha	Sand %	Silt %	Clay %	Texture	CEC
E23, W25-85-19-W5 NW Plains	KCl-Polyer - Solids	0.12	1.0	2	1	488	32	44	24	L	24.4
LSD 4-5-65-4-W4 NE Plains	Fresh Water Gel - Solids	0.22	1.3	6	1	456	36	32	32	CL	20.6
LSD 14,15-10-65-4-W4 NE Plains	NaCl - Solids	0.36	2.5	8	1	585	42	34	24	L	32.4

* Solids analyzed by a commercial laboratory.
Liquids analyzed by the ERCB Laboratory.

Appendix Table A7. Multielement Determination by I.C.P. Scan of Acid Digests and 1:20 Dilutions (pH adjusted to 5) of Solids and Liquids from Three Sumps.

Element ppm ug/gm dry weight basis		E-23,W-25-85-19-W5 NW Plains KCl-Polymer			LSD4-5-65-4-W4 NE Plains Fresh Water Gel			LSD14,15-10-65-4-W4 NE Plains NaCl		
		SOLIDS			SOLIDS			SOLIDS		
		Total	Dilution (1:20)	LIQUIDS	Total	Dilution (1:20)	LIQUIDS	Total	Dilution (1:20)	LIQUIDS
Aluminum	(Al)	7,100	0.02	0.04	5,500	0.01	0.04	7,050	0.44	4.54
Boron	(B)	33.8	0.1	1.19	26.3	0.23	1.6	40.6	0.42	0.2
Barium	(Ba)	273	0.5	1.48	104	0.78	1.4	108	0.84	0.45
Beryllium	(Be)	0.5	<.001	<.001	0.45	<.001	0.001	0.4	< 0.001	<0.001
Cadmium	(Cd)	<.01	0.002	<.001	<.01	<.001	<.001	<.01	< 0.001	<0.001
Calcium	(Ca)	28,500	550		17,400	205		45,100	1,100	
Cobalt	(Co)	5.9	0.023	0.014	6.62	0.02	0.038	5.4	0.009	0.007
Copper (Cu)	(Cu)	21.9	0.007	0.030	16.3	0.01	0.011	15.1	0.023	0.072
Chromium	(Cr)	27.4	0.006	0.16	9.53	<.001	0.002	107	0.1	0.45
Iron	(Fe)	21,500	0.47	9.11	12,990	0.52	0.01	13,200	1.12	10.0
Lead	(Pb)	29.8	<.05		26.0	<.05		44.2	<.05	
Lithium	(Li)	11.2	0.014	0.14	6.0	0.02	0.09	12.1	0.03	0.064
Magnesium	(Mg)	6,580	51.5		3,400	23.6		9,090	110	
Manganese	(Mn)	238	1.91	1.63	225	1.26	3.72	223	1.84	0.29
Molybdenum	(Mo)	14.7	0.016	0.098	12.0	0.006	0.09	15.1	0.014	0.053
Nickel	(Ni)	25	0.064	0.11	22.7	0.085	0.13	19.4	0.093	0.089
Potassium	(K)	1,096	7.7		922	7.9		1,085	7.3	
Silicon	(Si)	2,610	9.8		1,592	9.9		3,070	36.8	
Sodium	(Na)	860	19.0		2,300	87		31,800	650	
Strontium	(Sr)	60.8	0.92	3.15	67.8	1.33	3.24	98.5	2.26	1.13
Vanadium	(V)	17.7	<.001	0.02	16.2	0.001	0.02	18.2	0.004	0.032
Zinc	(Zn)	69.3	0.024	0.032	60.6	0.07	0.056	96.0	0.21	0.21

Note: Analyzed by a commercial laboratory.

Appendix Table A8. Toxicity of a KCl Sump, a Fresh Water Gel Sump and a NaCl Sump Determined by 96 hour Trout Test.

		COMMERCIAL LAB RESULT		ERCB LAB RESULT
		SOLIDS		
		Calculated LD_{50}[1]		
Location	Sump Type	Filtrate	24 hour Leachate	LIQUIDS
E23, W25-85-19-W5 NW Plains	KCl-Polymer	25%	> 20%	1[2] dead @ 8 hrs. 1 dead @ 27.5 hrs. 1 okay @ 100 hrs.
LSD 4-5-65-4-W4 NE Plains	Fresh Water Gel	14%	11%	3[3] dead < 1.5 hrs.
LSD 14, 15-10-65-4-W5 NE Plains	NaCl	9.7%	4.2%	3[4] okay @ 98 hrs.

[1] Concentration of medium at which 50% of the test population survive.

[2] Sample as received.

[3] Sample as received.

[4] Original sample had to be diluted 1:5 in order to render it non-toxic.

Appendix Table A9. Toxicity of a KCl Sump, a Fresh Water Gel Sump and a NaCl Sump Determined by Microtox Assay.

Location	Sump Type	$EC20^{1}_{(5)}{}^{2}$	$EC20_{(15)}$	$EC50_{(5)}$	$EC50_{(15)}$
E23, W25-85-19-W5 NW Plains	KCl-Polymer Liquids	52	39	100	100
LSD 4-5-65-4-W4 NE Plains	Fresh Water Gel Liquids	32	27	100	66
LSD 14, 15-10-65-4-W5 NE Plains	NaCl Liquids	10	11	15	16

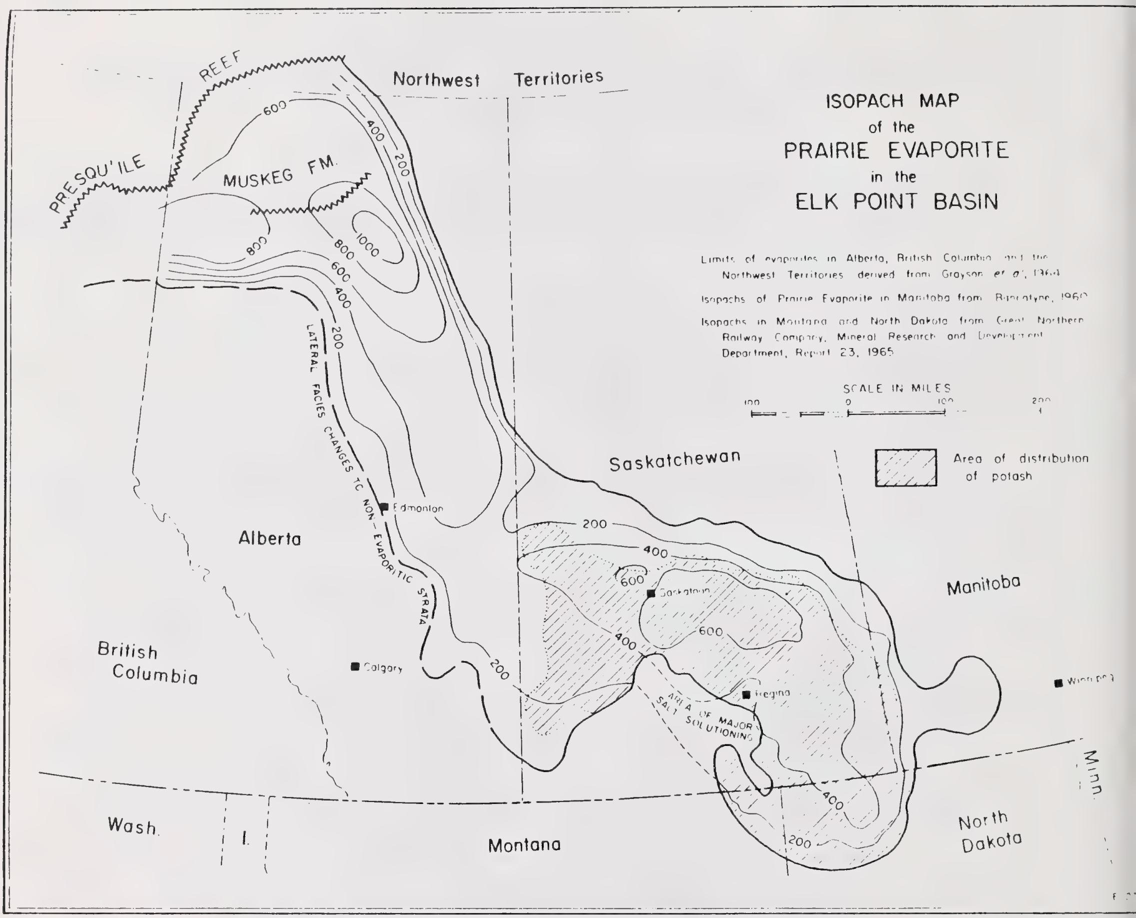
[1] EC20 and 50: effective concentration of toxicant (or test sample) causing a 20% (or 50%) decrease in the Microtox Reagent light output.

[2] (5) or (15) after 5 or 15 minutes

Interpretation:

MICROTOX VALUES		Toxicity	Trout Bioassay
EC 20	EC 50		
0-30	0-50	Toxic	Dead fish
30-50	50-90	Slightly Toxic	Some dead fish at "x" hours; loss of orientation
>50	>90	No significant effect - passes	Fish OK at 96 hours

Analysis conducted by ERCB Laboratory.


ISOPACH MAP
of the
PRAIRIE EVAPORITE
in the
ELK POINT BASIN
Limits of evaporites in Alberta, British Columbia and the Northwest Territories derived from Grayson et al, 1964
Isopachs of Prairie Evaporite in Manitoba from Bannatyne, 1960
Isopachs in Montana and North Dakota from Great Northern Railway Company, Mineral Research and Development Department, Report 23, 1965
SCALE IN MILES
100
0
100
200
Area of distribution of potash
Northwest Territories
PRESQU'ILE
REEF
MUSKEG FM.
600
400
200
800
1000
800
600
400
200
LATERAL FACIES CHANGES TO NON-EVAPORITIC STRATA
Edmonton
Alberta
British Columbia
Calgary
Saskatchewan
200
400
600
Saskatoon
600
400
200
AREA OF MAJOR SALT SOLUTIONING
Regina
400
200
Manitoba
Winnipeg
Minn.
North Dakota
Montana
Wash.
I.

Appendix Figure A1. Isopach Map of the Prairie Evaporite.

APPENDIX B1. PARENT MATERIALS AND SOILS

Most of Alberta's soils have formed on surficial materials deposited during the last glaciation. Other soils have formed on glacial deposits reworked by water or wind, or directly on bedrock. Parent material largely determines the physical properties of the soil formed. Characteristics such as texture, permeability, fracturing, bulk density, stoniness, and stratification are dependent on parent material. They influence soil capability for forestry and agriculture as well as relative susceptibility to impact of drilling waste disposal. Parent material characteristics to be considered for drilling wate disposal are summarized in Table B1. A provincial overview of characteristics of the major soils is given in Table B2.

Appendix Table B1. Parent Material Characteristics of Importance to Drilling Waste Disposal.

PARENT MATERIAL*	ASSOCIATED LANDFORM/TOPOGRAPHY	DOMINANT TEXTURES	IMPORTANT FEATURES	SUSCEPTIBILITY TO	
				Compaction	Erosion
Eolian	- dunes - gently undulating plains	sands loamy sands no stones well sorted	- very low water holding capacity - rapid permeability - high potential for deep percolation - very low fertility - difficult to revegetate	low	by wind, severe
Fluvial	- floodplains - terraces - undulating plains - often dissected	sands silts gravels, cobbles rarely clays generally well sorted stratified occasionally massive non-sorted	- flooding on floodplains - low water holding capacity - permeability varies with texture and stratification - high potential for lateral flow - groundwater often shallow on recent floodplains - sands/gravels have low fertility and are difficult to revegetate	low	by water on floodplains and by flow off adjacent highlands
Fluvial-Eolian	- undulating plains	sands loamy sands no stones well sorted stratified	- low water holding capacity - rapid permeability - high potential for deep percolation - often overlies finer materials (lacustrine, till) - low fertility - may be difficult to revegetate	low	by wind, moderate
Lacustrine and Lacustro-till	- level to undulating plains - rarely hills	silty clays silty clay loams clays clay loams few to no stones well to moderately sorted stratified	- high to very high water holding capacity - slow to very slow permeability - low potential for deep percolation - often overlies slightly more permeable materials (till) - depressions often contain wetlands - water ponding after rains or snowmelt - difficult to work if too wet or too dry	high	by water, especially on long slopes
Fluvial-Lacustrine	- undulating plains - rarely hills	silts sandy loams loams	- moderate water holding capacity - permeability varies with texture and stratification - moderate potential for lateral flow and deep percolation - depressions often contain wetlands	moderate	by water on slopes

* Definitions provided in the Glossary.

APPENDIX B

ENVIRONMENT FOR DRILLING WASTE DISPOSAL

Appendix Table B1. Parent Material Characteristics of Importance to Drilling Waste Disposal (Continued).

PARENT MATERIAL*	ASSOCIATED LANDFORM/TOPOGRAPHY	DOMINANT TEXTURES	IMPORTANT FEATURES	SUSCEPTIBILITY TO	
				Compaction	Erosion
Till (Plains)	- undulating plains - hills - hummocky terrain	loams, clay loams and clays few stones to very stony non-stratified	- moderate to high water holding capacity - moderate to slow permeability - some potential for lateral percolation through cracks and sandy lenses - generally low potential for deep percolation - wetlands abundant in hilly and hummocky areas	moderate to high	by water on slopes
Till (Foothills/ Mountains)	- strongly rolling hills - ridges - steeply sloping	sandy loams, silt loams and loams few to many coarse fragments non-stratified	- low to moderate water holding capacity - rapid to moderate permeability depending on coarse fragment content - high potential for lateral and deep percolation through cracks and sandy lenses - wetlands restricted to valleys between ridges - low fertility - difficult to revegetate	low to moderate	by water on slopes
Weathered Bedrock (Plains)	- undulating plains - hilly	silts and clays, rarely sands no stones often stratified	- high water holding capacity - slow to very slow permeability - low potential for deep percolation but may have lateral percolation through coarser strata - water ponding after rains or snowmelt - high salinity/sodicity in marine bedrocks - low fertility - difficult to revegetate	moderate to high	by water on slopes
Weathered Bedrock (Foothills/ Mountains)	- strongly rolling - often ridged - steeply sloping	sands and silts many bedrock fragments often stratified	- low to moderate water holding capcity - rapid to moderate permeability depending on coarse fragment content and texture - high potential for lateral and deep percolation through cracks - low fertility - difficult to revegetate	low	- by water on slopes - low slope stability
Organic	- depressional peat lands	peat	- very high water holding capacity - high water table resulting in anaerobic conditions - highly susceptible to groundwater contamination - difficult to traverse with machinery	low	nil

* Definitions provided in the Glossary.

Appendix Table B2. Characteristics of the Soil Zones of Alberta.

Soil Zone/Major Soil	Climate	Natural Vegetation; Land Use	Implications for Waste Disposal
BROWN thin (5-15 cm) brown surface horizon; low organic matter content (2%); pH neutral to alkaline; high base saturation; low to moderate salinity	Semi-arid: Annual precipitation averages 300 mm. Summer: Low rainfall, very warm temperatures, frequent high winds. Wind erosion hazard; difficult to establish vegetation. Winter: Cold temperatures, winds and snow storms with appreciable snow accumulation at times. Periodic warm Chinook winds. Alternating cold and warm temperatures cause variable frost depth.	short grass prairie; rangeland, strip cropping	high wind erosion hazard; dry conditions reduce rates of biological decomposition; establishment of vegetation is difficult; minimum of leaching
DARK BROWN 10-20 cm dark brown surface horizon; 4% organic matter; slightly acid to neutral; high base saturation; low to moderate salinity	Semi-arid: Annual precipitation averages 350 mm. Summer: same as Brown Soil Zone Winter: same as Brown Soil Zone	tall grass prairie; rangeland and cropping	generally slightly more favorable than Brown Zone
BLACK 25-35 cm black surface horizon; 8% organic matter; acid to neutral; high base saturation; low salinity	Dry-Subhumid: Annual precipitation averages 380 mm in the SE corner and 460 mm in the north and west. Summer: Ample rainfall, warm to cool temperatures, occasional heavy and prolonged rainfall. Winter: Cold temperatures, soils frozen to great depth (1-2 m) most winters. Occasional thaws result in slippery conditions.	mixed prairie and parkland; cropping	most favorable summer climate for biological decomposition; relatively easy to establish vegetation; soil leaching occurs

Appendix Table B2. Characteristics of the Soil Zones of Alberta (Continued).

Soil Zone/Major Soil	Climate	Natural Vegetation; Land Use	Implications for Waste Disposal
DARK GRAY 10-15 cm dark gray surface horizon; organic matter content less than for Black; otherwise similar	Similar to Black except in Ft. Vermilion area which may be deficient in rainfall.	parkland and forest; cropping and rangeland	similar to Black
GRAY thin leaf litter overlying a brown to gray platy horizon (Ae) and finer textured; strongly structured B horizon; low fertility; moderate to strong acidity; high base saturation; low salinity	Subhumid: Annual precipitation varies from 480-560 mm in the SW to 300-350 mm in the north. Summer: as for Black Winter: as for Black	dominantly deciduous forest with some coniferous; forest, rangeland and cropping	Must salvage as much topsoil as possible to enhance decomposition and improve seedbed. Fertilization recommended high runoff potential.
UNDIFFERENTIATED MOUNTAIN COMPLEX thin leaf litter overlying a brown to gray mineral horizon; shallow, stony soils common; low fertility; low salinity. Brunisolic, Luvisolic and Regosolic Soils	Humid: Annual precipitation averages over 600 mm. Summer: High rainfall and cool temperatures; occasional heavy and prolonged rainfall. Winter: Cold temperatures with deep snow accumulation. Periodic warm Chinook winds.	coniferous forest; forest and limited rangeland	Similar to Gray Zone but higher potential for runoff, erosion and surface water pollution on steeper slopes.

Appendix Table B3. Cross-section of typical water quality for rivers and lakes in Alberta (units are mg/l).

	NORTH SASKATCHEWAN RIVER @ DEVON (REYNOLDSON,1983)	BEAVER RIVER NEAR COLD LAKE (BABIN&TREW,1985)	CROWSNEST ABOVE COLEMAN (SCHONEKESS&HAMMOND,1979)	BLOOD INDIAN RESERVOIR (CHARLTON,1986)	EAGLE LAKE (CHARLTON et al.1982)	MOORE LAKE (TREW et al.1983)	COLD LAKE (TREW et al.1983)
TOTAL DISSOLVED SOLIDS	188	260	191	1559	-	397	142
CALCIUM	43	47	-	31	24	15	32
BICARBONATE	149	260	-	356	522	386	160
SODIUM	4.1	27.0	3.0	471	200	88	8.7
SULPHATE	35	24	45	816	-	18	4
POTASSIUM	0.8	4.3	0.3	9.5	12.3	6.6	1.9
CHLORIDE	1.3	9.0	1.6	10.2	21.0	20.4	1.1
pH	7.6 - 8.4	7.7 - 8.2	7.3 - 8.5	8.5 - 9.1	8.7	-	-
PHENOLS	0.002	-	0.002	0.010	0.004	-	-
ARSENIC	<.0005	0.0009	-	-	-	-	-
CADMIUM (tot)	<.001	0.002	-	-	0.001	-	-
CHROMIUM (ext)	<.015	0.006	-	-	0.003	-	-
COPPER (ext)	<.003	0.004	-	-	-	-	-
LEAD (tot)	<.004	0.008	-	-	0.004	-	-
IRON (ext)	0.215	0.39	0.05	0.04	0.49	-	-
AMMONIA	<0.1	0.019	0.05	0.10	0.06	0.032	0.015
TOTAL ORGANIC CARBON	3.1	22.3	2.0	16.4	-	-	-

APPENDIX B3. GROUNDWATER

Theory of Flow

The flow velocity of groundwater through porous subsurface materials is a function of the hydraulic gradient and of the physical properties of both the media and the fluid. It is expressed by Darcy's Law:

$$v = Ki$$

where: v = Darcy's velocity (m/s)
K = hydraulic conductivity (m/s)
i = hydraulic gradient (dimensionless)

Darcy's law is valid only for laminar flow conditions, which are characterisitic of groundwater movement in the porous media. It describes the flow of groundwater from areas of high hydraulic head to areas of low hydraulic head. The direction of flow is dependent only on the distribution of head within the water. Therefore, either upward or downward flow is possible.

The most variable factor in the flow of groundwater is the hydraulic conductivity (K). Values for K range many orders of magnitude. Typical numbers for various unconsolidated deposits are shown below. The hydraulic conductivity has high values for gravel and very low values for clay. Therefore, water located in gravel will flow more freely than water located in clay, all other factors considered constant.

Values of Hydraulic Conductivity (after Todd, 1959).

Type of Material	Clean gravel	Clean sands; mixtures of clean sands and gravels	Very fine sands; silts; mixtures of sand, silt, and clay; glacial till; stratified clays; etc.		Un-weathered clays
Flow characteristics	Very Good	Good Aquifers	Pervious	Semi-Pervious	Impervious
Hydraulic Conductivity (m/s)	10^{1} 10^{0}	10^{-1} 10^{-2} 10^{-3}	10^{-4} 10^{-5}	10^{-6} 10^{-7}	10^{-8} 10^{-9}

The hydraulic gradient (i) is a measurement of the change in hydraulic head over distance and may be viewed as the driving force behind groundwater movement. If there is a large change in head over a relatively short distance, the hydraulic gradient will be high. The converse is true for a small change in head. Values of the hydraulic gradient are commonly less than 1, and are often in the range of 0.1 to 0.01.

Geologic units in which groundwater flows can be classified according to their ability to hold and transmit water under ordinary hydraulic gradients. An aquifer is a saturated geologic unit that both contains and can transmit water (e.g. sand, gravel). On the other hand, an aquifuge neither contains nor can transmit water (e.g., massive granite). Between these hydrogeological extremes is an aquitard, which contains, but cannot transmit water (e.g. clay).

It is therefore an aquifer which will transport groundwater and any contamination. Aquifers can be confined or unconfined. An unconfined aquifer, also called a water-table aquifer, has the water table as the upper boundary (Figure B1). A confined aquifer is situated between two aquitards or aquifuges. If a well located in a confined aquifer has a water level above the top of the aquifer, it is under artesian conditions.

Both groundwater flow and contaminant migration are complicated by the effects of heterogeneity and anisotropy. Many aquifers exhibit a hydraulic conductivity which varies over distance and also is different depending on the direction of groundwater flow. An important example of this is when the media is fractured, as is often the case with rock and clay deposits. These effects are difficult to define accurately and result in the fingering and layering of groundwater flow. Hence, contaminant migration may, in localized zones, be faster or slower than predicted.

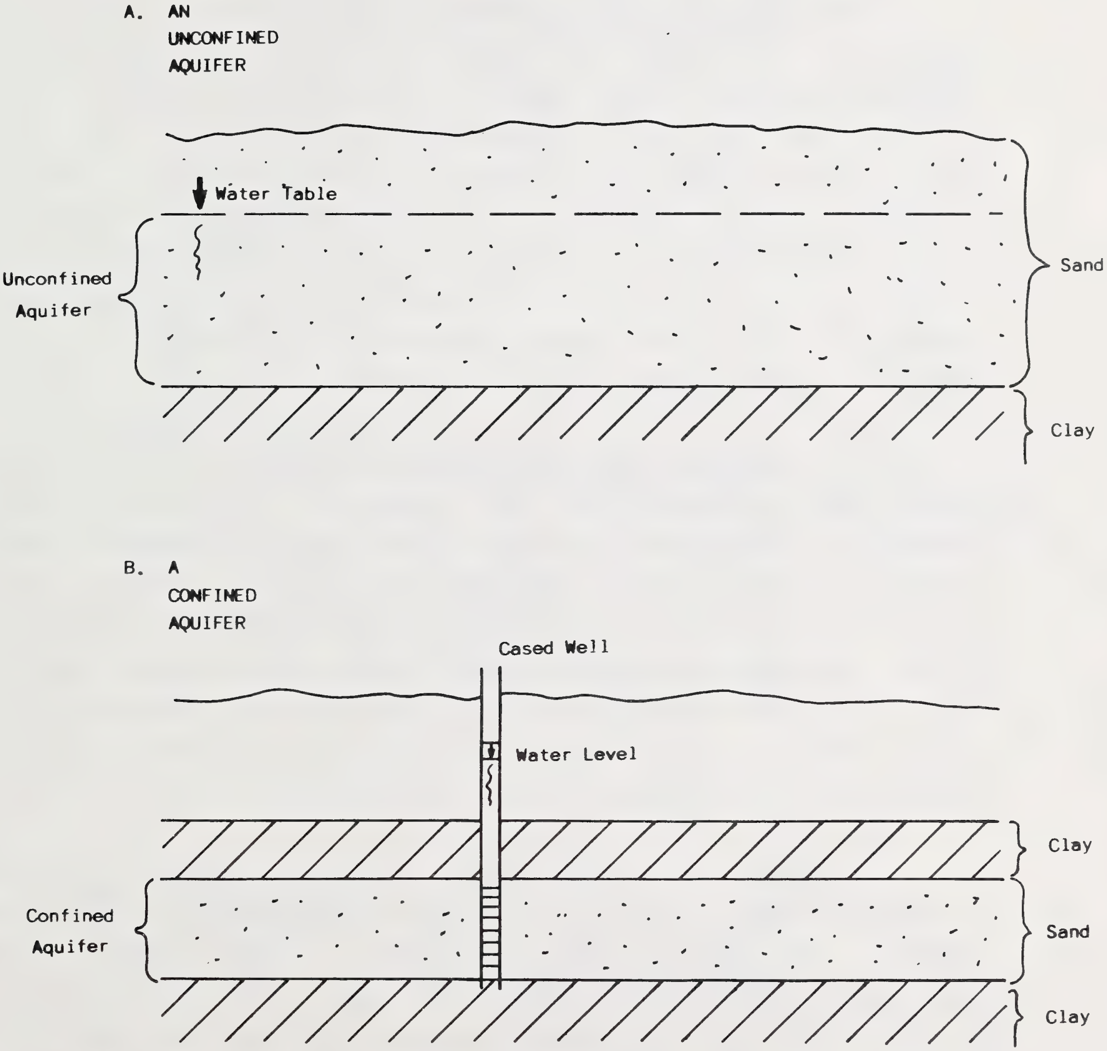


Figure B1. Typical Unconfined and Confined Aquifers.

Groundwater Features

The direction of flow varies with the groundwater circulation regime. In a recharge zone, the predominant flow is downwards and contaminant migration will also be in this direction (see Figure 4.2). A transitional zone has a horizontal flow which would lead to the lateral transportation of contaminants. In a discharge zone, the predominant flow is upwards and contaminants are generally retained at or near the surface. Thus, the best zone for the surface contaminant of drilling wastes would be a discharge zone. Certain locations have a direction of flow which varies according to the season. In this instance it is the net flow which is of interest.

The depth to the water table (groundwater surface) also impacts on the migration of any contaminants, particularly organic pollutants. The aerobic decay of organic compounds is generally much greater and more complete than anaerobic processes. Therefore, near surface aerobic processes in the unsaturated zone are very important. If the saturated groundwater system is well below the ground surface then a large zone of aeration will exist through which contaminants must travel, allowing greater degradation. Such processes are particularly important when spreading waste on the ground surface.

Aquifers can be classified as either deep (hundreds of metres) or shallow (see Figure B3). In Alberta, deep aquifers are present in bedrock. Such units are typically permeable sandstone, conglomerate or coal beds as well as other fractured rock types. Since there is usually a thick layer of low hydraulic conductivity rock overlying these aquifers, they are confined and the potential for contamination due to drilling waste disposal is minimal.

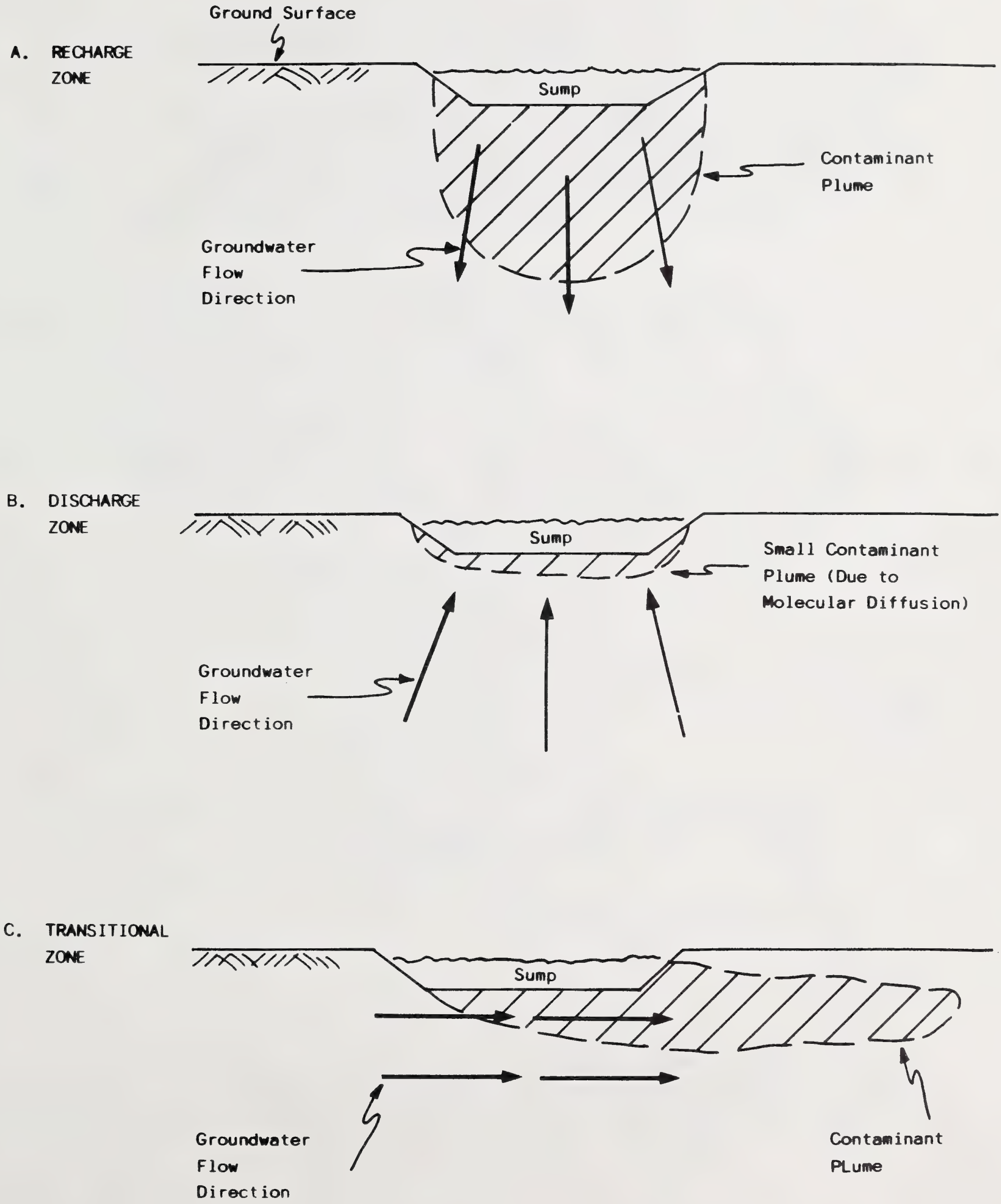
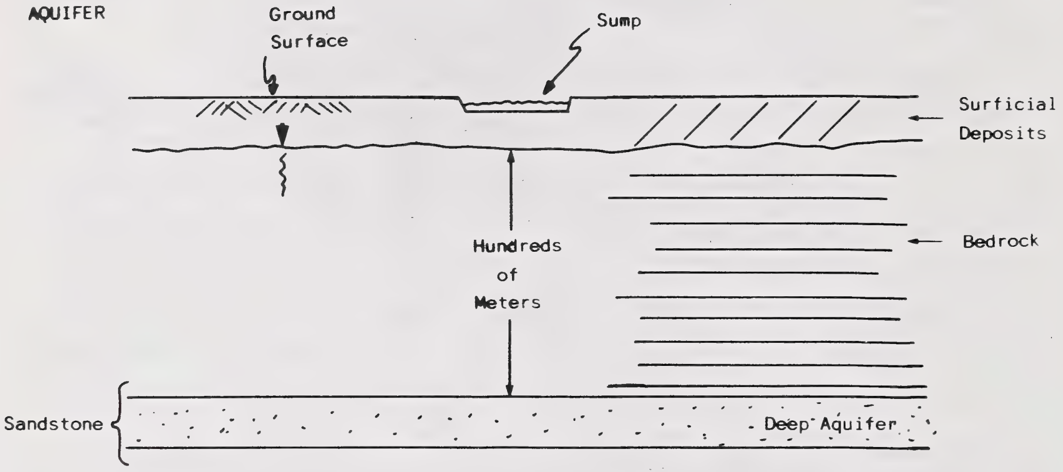

A. RECHARGE ZONE
Ground Surface
Sump
Contaminant Plume
Groundwater Flow Direction
B. DISCHARGE ZONE
Sump
Small Contaminant Plume (Due to Molecular Diffusion)
Groundwater Flow Direction
C. TRANSITIONAL ZONE
Sump
Groundwater Flow Direction
Contaminant PLume

Figure B2. Groundwater Circulation Regimes.

A. RELATIVELY DEEP AQUIFER



B. RELATIVELY SHALLOW AQUIFER

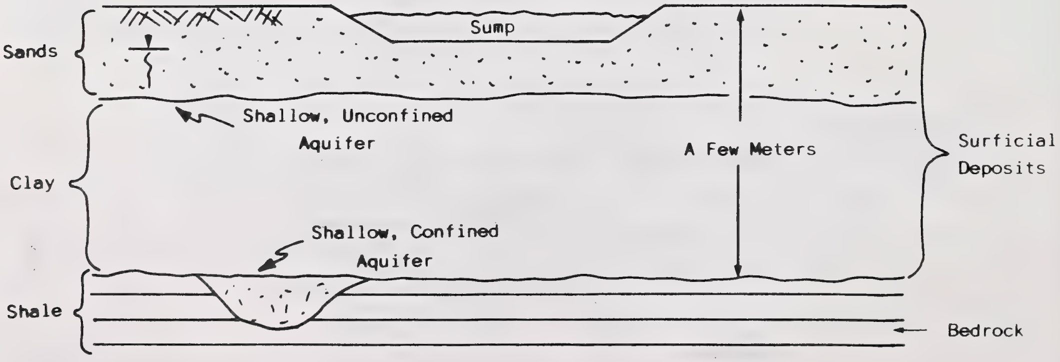


Figure B3. Examples of Deep and Shallow Aquifers.

Shallow aquifers may be located few to tens of metres below ground surface. Quaternary (surficial) sand and gravel layers are an important source of domestic water supply for the province, and whether confined or unconfined, would be subject to pollution by contaminant movement. Thus, it is primarily the surficial aquifers that are of concern when disposing of drilling wastes at or near surface.

Proximity to nearby water supply sources, such as springs and dugouts is another important criteria. Every attempt should be made to avoid aquifers, which are, or may become, a water supply source.

Appendix Table B4. Classification of Dissolved Inorganic Constituents in Groundwater.

MAJOR CONSTITUENTS (greater than 5 mg/1)

- Bicarbonate
- Calcium
- Chloride
- Magnesium
- Silicon
- Sodium
- Sulfate
- Carbonic acid

MINOR CONSTITUENTS (0.01-10.0 mg/1)

- Boron
- Carbonate
- Fluoride
- Iron
- Nitrate
- Potassium
- Strontium

TRACE CONSTITUENTS (less than 0.1 mg/1)

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium
- Bismuth
- Bromide
- Cadmium
- Cerium
- Cesium
- Chronium
- Cobalt
- Copper
- Gallium
- Germanium
- Gold
- Indium
- Iodide
- Lanthanum
- Lead
- Lithium
- Manganese
- Molybdenum
- Nickel
- Niobium
- Phosphate
- Platinum
- Radium
- Rubidium
- Ruthenium
- Scandium
- Selenium
- Silver
- Thallium
- Thorium
- Tin
- Titanium
- Tungsten
- Uranium
- Vanadium
- Ytterbium
- Yttrium
- Zinc
- Zirconium

Source: Davis and De Wiest, 1966
(From: Freeze and Cherry, 1979)

Note: mg/1 is equivalent to ppm

APPENDIX C

TOLERABLE LEVELS OF WASTE CONSTITUENTS IN THE ENVIRONMENT

APPENDIX C1. ANALYSIS PROCEDURES

ANALYSIS OF LIQUIDS PORTION

PARAMETER	UNIT REPORTED	NAQUADAT CODE (Environment Canada, 1985)	REFERENCE
MINIMUM REQUIRED			
Dissolved Calcium (Ca)	mg/l	20103	Environment Canada, 1974
Dissolved Magnesium (mg)	mg/l	12102	Water Quality Branch, 1979
Dissolved Sodium (Na)	mg/l	11103	Same as above
Dissolved Potassium (K)	mg/l	19103	Same as above
Dissolved Chloride (Cl)	mg/l	17203	Same as above
Dissolved Sulphate (SO_4)	mg/l	16306	Water Quality Branch, 1979
Carbonate (calculated) (CO_3)	mg/l	06301	American Public Health Assoc., 1967, p.52
Bicarbonate (calculated) (HCO_3)	mg/l	06201	American Public Health Assoc., 1967, p.52
Nitrate - Nitrogen	mg/l		
Specific Conductance (EC) (Electrical Conductivity)	mS/cm	02041	Environment Canada, 1974
Trout Bioassay (12 fish; filtrate)	LD_{50}		Environment Canada, 1980
or			
Microtox	EC_{20} and EC_{50}		Beckman Microtox Analyzer as described by the manufacturer
SAR			calculated
OPTIONAL			
Total Dissolved Solids (TDS) (calculated)	mg/l		
Metals			
Total Boron (B)	mg/l		American Public Health Assoc., 1967, p.72
Total Cadmium (Cd)	mg/l	48002	Environment Canada, 1974
Total Chromium (Cr)	mg/l	-	American Public Health Assoc., 1960, p.109
Total Copper (Cu)	mg/l	29005	Environment Canada, 1974
Total Nickel (Ni)	mg/l	28003	Environment Canada, 1974
Total Zinc (Zn)	mg/l	30005	Environment Canada, 1974

CONVERSION OF LAB RESULTS INTO DISPOSABLE AMOUNTS

1. Soluble Ions and Metals

$mg/l \times 0.001 = kg/m^3$

kg/m^3 x estimated volume of liquids portion (m^3) =
amount to be disposed (kg)

It is recommended that lab results be reported in kg/m^3 of liquids sample.

2. EC and pH results are directly compared to acceptable values.

3. Trout Bioassay and Microtox

LD_{50} is the effective concentration at which 50% of the test population survive; the lower this value, the higher the toxicity. In an actual field situation the waste should not be applied at this concentration, but at a much lower concentration such as one tenth of the LD_{50} ($0.1 \times LD_{50}$) (Henderson and Tarzwell, 1957). A quick test can initially be performed with 2 to 3 fish in the undiluted sample for indication of toxicity (American Public Health Association, 1960).

EC 20 and EC 50 values indicate the effective concentration of the test sample at which a 20% or 50% decrease in the microtox reagent light output occurs. In order to be disposable, EC 20 of the sample should be greater than 50 ($EC\ 20 > 50$) and EC 50 should be greater than 90 ($EC\ 50 > 90$) after 15 minutes.

ANALYSIS OF SOLIDS (SLUDGE) PORTION

Analysis may be conducted on liquids, liquids and solids, or solids, portions of the sludge samples. Care is needed in determining moisture contents of field and saturated samples to convert lab results to actual quantities of constituents in the solids portion of a sump. Volumes of sludge in the sump must be determined reasonably accurately. Procedures for analyzing soils and solids are given below. Agreement among commercial and government laboratories is needed regarding analytical and reporting procedures.

PARAMETER	UNIT REPORTED	REFERENCE
MINIMUM REQUIRED		
Gravimetric Moisture content (oven-dry basis)	%	
Bulk Density (BD)	g/cm^3	McKeague, 1978 (2.2)
Saturation Percentage (SP)	%	Richards, 1954
Soluble Ions in Saturated Paste Extract		McKeague, 1978 (3.21)
Calcium (Ca)	meq/l	
Magnesium (Mg)	meq/l	
Sodium (Na)	meq/l	
Potassium (K)	meq/l	
Sulphate (SO_4)	meq/l	
Chloride (Cl)	meq/l	
Carbonate (CO_3)	meq/l	
Bicarbonate (HCO_3)	meq/l	
Sodium Adsorption Ratio (SAR) (calculated from soluble ions)	--	McKeague, 1978 (3.26)
Electrical Conductivity (EC)	mS/cm	Environment Canada, 1980
pH	-	McKeague, 1978 (3.14)
Trout Bioassay (12 fish; 24 hour leachate)	LD_{50} in %	Environment Canada, 1980
or		
Microtox bioassay	EC 20 and 50 in %	
OPTIONAL		
Texture	% S, Si, C	McKeague, 1978 (2.11)
Metals		
Hot water soluble Boron (B)	ug/g	McKeague, 1978 (4.61)
Total Cadmium (Cd)	ug/g	ICP-Scan, Page et al., 1982
Total Chromium (Cr)	ug/g	ICP-Scan, Page et al., 1982
Total Copper (Cu)	ug/g	ICP-Scan, Page et al., 1982
Total Mercury (Hg)	ug/g	ICP-Scan, Page et al., 1982
Total Nickel (Ni)	ug/g	ICP-Scan, Page et al., 1982
Total Lead (Pb)	ug/g	ICP-Scan, Page et al., 1982
Total Zinc (Zn)	ug/g	ICP-Scan, Page et al., 1982
Exchangeable Cations		McKeague, 1978 (3.32)
Ca	meq/100 g	
Mg	meq/100 g	
Na	meq/100 g	
K	meq/100 g	

CONVERSION OF LAB RESULTS INTO DISPOSABLE AMOUNTS

1. Soluble Ions

meq/l x milli-equivalent weight = mg/l of ion in saturated paste extract

$$\text{mg/l in saturated paste extract} \times \frac{\text{sp}}{100} = \text{mg/kg of sample (oven-dry basis)}$$

$$\begin{array}{c}\text{mg/kg of sample}\\\text{(oven-dry basis)}\end{array} \times \left(\frac{100}{100 + \%\ \text{moisture grav.}}\right) = \begin{array}{c}\text{mg/kg of sample}\\\text{(wet basis)}\end{array}$$

$$\text{mg/kg (wet)} \times \text{BD (g/cm}^3) \times \frac{\text{kg}}{1000\text{g}} \times \frac{1000\ \text{cm}^3}{1} = \text{mg/l of original sample}$$

$$\text{kg/m}^3 \times \text{Volume of Solids Portion (m}^3) = \text{Amount to be Disposed (kg)}$$

Milli-equivalent Weights (meq-wt)

Calcium - 20 mg	Chloride - 35.5 mg
Magnesium - 12.2 mg	Sulphate - 48 mg
Sodium - 23 mg	Bicarbonate - 61 mg
Potassium - 39.1 mg	Carbonate - 30 mg

It is recommended that the analytical laboratories report results in kg/m^3 of original sample, in order to avoid confusion in making conversions from meq/l or mg/l.

2. SAR, EC, pH results are directly compared to acceptable values.

3. Trout Bioassay and Microtox

LD$_{50}$ is the effective concentration at which 50% of the test population survive; the lower this value, the higher the toxicity. In an actual field situation the waste should not be applied at this concentration, but at a much lower concentration such as one tenth of the LD$_{50}$ (0.1 x LD$_{50}$) (Henderson and Tarzwell, 1957).

EC 20 and EC 50 values indicate the effective concentration of the test sample at which a 20% or 50% decrease in the microtox reagent light output occurs. In order to be disposable, EC 20 of the sample should be greater than 50 (EC 20 > 50) and EC 50 should be greater than 90 (EC 50 > 90) after 15 minutes.

4. Metals

ug/g = mg/kg of sample (oven-dry basis)

$$\underset{\text{(oven-dry basis)}}{\text{mg/kg of sample}} \times \left(\frac{100}{100 + \%\text{ moisture grav.}}\right) = \underset{\text{(wet basis)}}{\text{mg/kg of sample}}$$

$$\underset{\text{(wet basis)}}{\text{mg/kg of sample}} \times \text{BD g/cm}^3 \times \frac{\text{kg}}{1000\text{ g}} \times \frac{1000\text{ cm}^3}{1} = \text{mg/l of original sample}$$

mg/l of original sample x 0.001 = kg/m^3 of original sample

kg/m^3 x Volume of Solids Portion (m^3) = Amount to be Disposed (kg)

It is recommended that the lab results be reported in kg/m^3 of original sample.

5. Exchangeable Cations

meq/100g x milli-equivalent weight x 0.1 = mg/kg of sample (oven-dry basis)

$$\underset{\text{(oven-dry basis)}}{\text{mg/kg}} \times \left(\frac{100}{100 + \%\text{ moisture grav.}}\right) = \underset{\text{(wet basis)}}{\text{mg/kg of sample}}$$

$$\underset{\text{(wet basis)}}{\text{mg/kg of sample}} \times \text{BD g/cm}^3 \times \frac{\text{kg}}{1000\text{g}} \times \frac{1000\text{ cm}^3}{1} = \text{mg/l of original sample}$$

mg/l of original sample x 0.001 = kg/m^3 of original sample

This amount for a certain cation, such as Na, is added to the soluble amount of the ion (see (1) and then the total amount (soluble + exchangeable) to be disposed is calculated:

kg/m^3 x Volume of Solids Portion (m^3) = Amount to be Disposed (kg)

It is recommended that the lab results be reported in kg/m^3 or original sample.

APPENDIX C2. CALCULATION OF MUD LOADINGS ON SOILS

The amount of mud (physical perspective) added to a soil is dependent on the textures and thicknesses of the mud and the soil. In the absence of research and field testing on mud-soil mixtures, the following guidelines are suggested:

1. Surface Crusting and Clod Formation

Submit separate representative samples (10 kg each) of mud and soil to a laboratory to test modulus of rupture on various mixtures of mud and soil, e.g. 20%, 40%, 60% mud. Specify to the lab the expected moisture content of the mud when it is to be disposed so that the lab can provide an appropriate application rate in m^3/ha or thickness.

The modulus of rupture is an index of the strength of materials and is applied for evaluating the cohesion of dry soils, particularly as related to surface crusting and clod formation. Modulus of rupture values are useful in assessing the germination and emergence potential of various materials.

As a guide, the following ratings may be used:

	Good	Fair	Poor	Unsuitable
Modulus of rupture (millibars)	<150	150-250	250-500	>500

Source: ASAC, 1981.

It is desirable that the final rating be "good".

Note, this is only one of the criteria that must be met; texture and chemical loading must also be within acceptable limits.

2. Soil Texture

For fine soils: Topsoils - heavy clays, clays, silty clays, silty clay loams, clay loams, sandy clays, sandy clay loams Subsoils - heavy clays

a) do not add mud - if the mud is finer textured than the soil.

b) add no more than 25%, i.e. 5 cm mud/20 cm mud and soil - if the mud is the same texture as the soil.

c) add as much as 50%, i.e. 10 cm mud/20 cm mud and soil - if the mud is coarser than the soil.

For medium and coarse soils: silts, silt loams, loams, sandy loams, loamy sands and sands.

a) add as much as 50%, i.e. 10 cm mud/20 cm mud and soil but do not make the final mixture finer than silty clay loam, clay loam or sandy clay loam.

3. Pot Trials

Prepare small (pot/bucket) mixtures of mud (to be disposed) and soil (from the proposed receiving area) in different proportions (20%, 40%, etc. mud), soak, oven dry (say at 50'C for 24 hours), then test soil tilth, structure, consistence, and ability to re-wet. Oven drying is recommended to simulate droughty, sun-baked conditions. If time permits a test of seed germination in the mixture may be warranted. These are clearly subjective procedures to test in a practical way the results of guidelines 1 and 2. Nevertheless, they should provide a clear indication as to whether final mixtures appear satisfactory or unsuitable. Application rates could be adjusted accordingly. Results of any such preliminary tests should be documented along with final recommended and applied rates. Two or three years later field performance should be evaluated against initial recommendations.

4. Field Application

The criteria for selection of application systems and equipment are dependent upon several factors:

- the form of the sludge (liquid, semi-solid or solid)
- the quantity
- the area application rate
- the frequency of application (one time, several times)
- time of year
- topography of area (Torrey, 1979)

Application methods and equipment for liquid and some semi-solid municipal sludges are summarized. Surface application is performed either by irrigation or tank vehicle. A fixed irrigation system is best suited where sludges are applied regularly. The tank truck provides flexibility in where to haul and where to apply the sludge. The use of a pumped discharge on the tank allows discharge over a wider area or from a roadway. Subsurface injection is considered if public nuisance from sludge application is a possibility.

Methods and equipment for application of semi-solid and solid sludges are summarized. The most economical methods for drilling mud sludges are probably surface application by tank vehicle of liquid sludges or spreading of semi-solid sludges.

Application Methods and Equipment for Liquid and Some Semi-solid Sludges.

Method	Characteristics	Topographical and Seasonal Suitability
SURFACE APPLICATION:		
Irrigation:		
Spray (sprinkler)	Large orifice required on nozzle; large power and lower labor requirement; wide selection of commercial equipment available; sludge must be flushed from pipes when irrigation completed.	Can be used on sloping land; can be used year-round if the pipe is drained in winter; not suitable for application to some crops during growing season; odor (aerosol) nuisance may occur.
Overland flow	Used on sloping ground with vegetation with no runoff permitted; suitable for emergency operation; difficult to get uniform area application.	Can be applied from ridge roads.
Tank truck	Capacity 500 or more than 2,000 gal; large volume trucks will require flotation tires; can use with temporary irrigation set-up; with pump discharge can spray from roadway onto field.	Tillable land; not usable with row crops or on soft ground.
Farm tank wagon and tractor	Capacity, 500 to 3,000 gal; larger volume will require flotation tires; can use with temporary irrigation set-up; with pump discharge can spray from roadway onto field.	Tillable land; not usable with row crops or on soft ground.
SUBSURFACE APPLICATION		
Flexible irrigation hose with plow furrow or disc cover	Use with pipeline or tank truck with pressure discharge; hose connected to manifold discharge on plow or disc.	Tillable land; not usable on wet or frozen ground.
Tank truck with plow furrow cover	500 gal commercial equipment available; sludge discharged in furrow ahead of plow mounted on rear of 4-wheel-drive truck.	Tillable land; not usable on wet or frozen ground.
Farm tank wagon and tractor:		
Plow furrow cover	Sludge discharged into furrow ahead of plow mounted on tank trailer, application of 170 to 225 wet tons/acre; or sludge spread in narrow band on ground surface and immediately plowed under, application of 50 to 125 wet tons/acre.	Tillable land; not usable on wet or frozen ground.
Subsurface injection	Sludge discharged into channel opened by a tillable tool mounted on tank trailer; application rate 25 to 50 wet tons/acre; vehicles should not traverse injected area for several days.	Tillable land; not usable on wet or frozen ground.

Source: Torrey, 1979.

Methods and Equipment for Application of Semisolid and Solid Sludges.

Method	Characteristics
Spreading	Truck-mounted or tractor-powered box spreader (commercially available); sludge spread evenly on ground; application rate controlled by over-the-ground speed; can be incorporated by discing or plowing.
Piles or windrows	Normally hauled by dump truck; spreading and leveling by bulldozer or grader needed to give uniform application; 4 to 6 inch layer can be incorporated by plowing.

Source: Torrey, 1979.

5. Field Incorporation

After applying the mud, a drying period may be required, then rototilling, discing and/or cultivating is recommended to mix the mud with the topsoil. Sufficient workings, perhaps over a period of time, to create a good mixture (seedbed) are recommended. Normal seeding/planting practices can then be employed to establish a vegetative cover.

APPENDIX C3. PERMISSIBLE TOTAL SALT LOADING

According to Soil Quality Criteria (A.S.A.C., 1981) it is desirable to maintain an electrical conductivity below 4 mS/cm or 2 mS/cm depending on the sensitivity of the crops. For trees an EC of 2 mS/cm would be appropriate.

The conversion of EC mS/cm to mg/l or ppm of salts depends on the prevalent ions in the solution. For Alberta, the following relationships are recommended:

Salt (mg/l) = 850 x EC mS/cm; if sulphates are dominant in the soil solution.

or

Salt (mg/l) = 640 x EC mS/cm; if chlorides are dominant in the soil solution.

(Stanley/SNL Consulting, 1978; USDA Salinity Handbook No. 60, 1954)

If saturation percentage, bulk density, and original salt levels (EC, SAR) of a soil are known, the maximum salt load for a certain layer of soil can be calculated. Assuming a saturation percentage of 45%, a bulk density of 1.2 g/cm^3, negligible background levels of salt, and a maximum EC of 4 mS/cm, the following maximum amounts of sulphate salts could be spread on 20 cm:

$$\text{Salt ppm or mg/l} \times \text{saturation \%} \times \text{soil bulk density g/cc} \times \text{soil depth cm} \times 10^8\text{cm}^2/\text{ha} \times \frac{1\text{ kg}}{1000\text{ g}} = \text{salt kg/ha}$$

4 mS/cm x 850 = 3400 ppm

$$\frac{3400}{1,000,000} \times \frac{45}{100} \times 1.2\text{g/cm}^3 \times 20\text{ cm} \times 10^8\text{cm}^2/\text{ha} \times \frac{1\text{ kg}}{1000\text{ g}} = 3672\text{ kg/ha}$$

If chlorides are dominant the salt load amounts to 2765 kg/ha.

If a maximum EC = 2 mS/cm is desired, such as in forested areas, the values would be halved to 1,836 kg/ha for sulphate dominated systems, and to 1,383 kg/ha for chloride dominated systems.

Note that adjustments are needed to accommodate site specific conditions, specifically, waste chemical properties, soil saturation percentage, bulk density, and depth of incorporation.

APPENDIX C4. PERMISSIBLE SODIUM LOADING

The permissible sodium loading depends on salinity, tolerable sodicity levels and background sodicity in the soil. Assuming an EC of 4 mS/cm and SAR of 8 is tolerable, the permissible SAR of the waste is estimated as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad \text{(ions measured in meq/l)}$$

Example Calculations:

	Original Soil	Waste Added*	Soil Plus Water
Na	<1	22	22
K	<1	2	2
Ca	3	8	11
Mg	2	3	5
EC	0.5	3.5	3.5
SAR	<1	9.4	7.8

* Assume dominantly sodium chloride, mixture of equal amounts of soil and mud, and 20 cm medium textured soil, hence: (From Procedures, Appendix C3).

$$\frac{3.5 \times 640 \times 0.5 \times 1.4 \times 20}{10} = 3{,}136 \text{ kg/ha salt added}$$

As a rule of thumb, if the SAR of applied wastes is less than 10, then soil sodicity would not become a limitation when soil EC <4 mS/cm. If SAR of the waste exceeds 10 then soil sodicity could become a problem.

It appears that when ERCB guidelines for land application of total salts, chlorides and sulphates are adhered to, and the permissible disposal area is reaonable (maybe 10 ha), a SAR or sodium problem should generally not occur. Testing is needed to determine whether this is in fact correct.

APPENDIX C5. WASTE DISPOSAL SCENARIOS

Possible disposal scenarios for surface spreading of wastes over a Luvisolic soil which is the most common soil in the forested areas of the province are presented in Appendix Tables C1-3. This can only be done in a very general sense because only limited data are available and sump contents are extremely variable. Many assumptions therefore had to be made to fill data gaps (see footnotes on tables). The disposal scenarios presented are low, medium and high volume sumps in combination with low and high concentrations of potentially limiting constituents in Alberta sumps/ muds. The numbers were taken from actual sump records and analysis data of liquids and solids portions. The area required for surface spreading was determined from the amount to be disposed and the permissible spread rate assuming that the wastes are incorporated into the upper 20 cm of soil. Constituents which required a large area (>1 ha) for disposal were identified as the most limiting constituents. Despite severe interpretive limitations several basic principles become evident from this exercise.

1. Freshwater Sumps/Muds (Appendix Tables C1, C2)

Chloride, sulphate and trace elements are the most limiting factors. At high concentrations of chlorides and sulphates the area required for disposal exceeds one hectare even for low volume sumps (6,000 bbl). The most limiting of the trace elements seems to be nickel. The area needed for disposal becomes impractical where the sump volume is high.

Spreading of clay solids on clay or heavy clay textured materials is not recommended, however spreading of 10 cm of clayey solids onto sandy loams, loamy sands or loams, seems to be a desirable disposal method. Disposal of muds on medium textured soils appears

Appendix Table C1. Example Spread Rate of Liquids, Fresh Water Composite Sump.

Constituent	Concentration in Sample	Quantity in[1] 1000 m^3 Sump	Baseline[2] Soil Properties	Permissible[3] Loading	"Safe" Spread Area
TDS (calc)	2,315 mg/l	2,315 kg	425 kg/ha	1700-425 kg/ha	1.8 ha
Cl	124 mg/l	124 kg		450 kg/ha	0.3 ha
SO4	939 mg/l	939 kg		230 kg/ha	4.1 ha
pH	7.9	7.9	6.5 kg/ha	5.5-8.5	-
				Amount Applied (on 178 ha)	
Na	580 mg/l (25 meq/l)	580 kg	<1 meq/l	141 kg/ha (6.1 meq/l)	
K	15 mg/l (.38 meq/l)	15 kg	<1 meq/l	3.6 kg/ha (0.9 meq/l)	
Ca+Mg	115 mg/l (7.2 meq/l)	115 kg	5 meq/l	28 kg/ha (6.8 meq/l)	
EC(esti)[4]	2.7	2.7	0.5	0.7	okay
SAR (calc)[5]	13	13	0.6	3.4	okay

Source: Table A5, Central Plains 19-28-W4.

Notes:

[1] Sump volume = 1000 m^3, approximately 6000 barrels.

[2] Soil = Gray Luvisol on till; None to Slight Limitations for surface disposal; Medium textured top 20 cm; Saturation % = 50; bulk density = 1.4 g/cc.

[3] Permissible loading kg/ha - baseline (kg/ha) = allowable addition kg/ha: Maintain EC below 2 mS/cm.

[4] EC approximately = $\frac{TDS}{850}$ (for sulphate system) = 2.7

[5] SAR = $\frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$ (ions in meq/l), consider equal amounts of Ca and Mg here.

Calculation Procedures

1. Determine concentration of constituents in kg/m^3, volume of sump in m^3, and quantity of each constituent to be disposed in kg.
2. Determine permissible loading either as maximum that can be applied (Cl and SO_4) or as maximum concentration tolerable in soil minus the background level (TDS_{calc} = EC x 650 or 850).
3. Determine minimum spread area based on TDS, Cl, SO_4 and, if known, heavy metals and trace elements.
4. Once the safe minimum spread area is known (4.1 ha in this example), the rate of application of Ca, Mg and Na can be determined and the final SAR (of waste applied or of combined soil and waste) estimated. If waste SAR <10, no problem; if SAR >10, then amendment may be added to reduce SAR. Calcium chloride or calcium nitrate in this case, not gypsum, is recommended because gypsum contains sulphate which is already limiting.

Appendix Table C2. Example Spread Rate of Solids, Fresh Water Gel Sump.

Constituent	Concentration[1] in Sample	Quantity in $100\ m^3$ Sump	Baseline[2] Soil Properties	Permissible[3] Loading	"Safe" Spread Area
Mineral material	40% (vol.)	$40\ m^3$	L	$10\ cm^3$	0.04 ha
TDS	2298 mg/l	230 kg	425 kg/ha	1275 kg/ha	0.18 ha
Cl	103 mg/l	10.3 kg	-	450 kg/ha	0.02 ha
SO_4	999 mg/l	100 kg	-	230 kg/ha	0.44 ha
pH	11.5	11.5	6.5	5.5-8.5	?
				Amount Applied (on 0.44 ha)	
Na	858 mg/l (37 meq/l)	86 kg	<1 meq/l	195 kg/ha	
K	11 mg/l (0.28 meq/l)	1.1 kg	<1 meq/l	2.5 kg/ha	
Ca+Mg	55 mg/l (2.75 meq/l)	5.5 kg	5 meq/l	12.5 kg/ha	
SAR[4]	32	32	0.6	15	
EC	4.2	4.2	0.5	<2	

Source: Table A6, Fresh Water Gel Solids.

Notes:

[1] Assume these lab values express concentration in mg/l of fluids plus solids, as submitted.

[2] Soil = Gray Luvisol on till; None to Slight Limitations for surface disposal; Medium textured top 20 cm; Saturation % = 50; bulk density = 1.4 g/cc.

[3] Assume you could add up to 10 cm of solid (dry or equivalent) to soil surface and mix with upper 10 cm of soil.

[4] There is about 1 cm of solid applied, therefore, ignore properties of solids deal with soluble salts only.

	Soil		Waste		Total
Na (meq/l)	1	+	8.5	=	9.5
Ca+Mg (meq/l)	5	+	0.6	=	5.6

$$SAR = \frac{9.5}{\sqrt{\frac{5.6}{2}}} = 5.7$$

Conclusion

SO_4 is the main limiting constituent, so when an adequate spread rate for SO_4 is attained, all oth constituents are within permissible limits. While the waste alone has an unacceptable SAR, mixing with t soil dilutes ion concentrations to make the final SAR acceptable.

Appendix Table C3. Example Spread Rate of Liquids, NaCl Sump.

Constituent	Concentration in Sample	Quantity in[1] 1000 m^3 Sump	Baseline[2] Soil Properties	Permissible[3] Loading	"Safe" Spread Area
TDS (calc)	138,016 mg/l	138,016 kg	425 kg/ha	855 kg/ha	161 ha
Cl	80,092 mg/l	80,092 kg	-	450 kg/ha	178 ha
SO_4	2,057 mg/l	2,057 kg	-	230 kg/ha	9 ha
pH	11.9	11.9	6.5	5.5-8.5	?
				Amount Applied (on 178 ha)	
Na	55000 mg/l (2391 meq/l)	55000 kg	<1 meq/l	309 kg/ha	
K	179 mg/l (4.6 meq/l)	179 kg	<1 meq/l	1 kg/ha	
Ca+Mg	221 mg/l (14 meq/l)	221 kg	5 meq/l	1.2 kg/ha	
SAR	920	920	0.6	65	add amendment[6]
EC	216	216	0.5	1.2	okay

Source: Table A6.

Notes:

[1] Sump volume = 1000 m^3, approximately 6000 barrels.

[2] Soil = Gray Luvisol on till; None to Slight Limitations for surface disposal;
Medium textured top 20 cm; Saturation % = 50; bulk density = 1.4 g/cc.

[3] Permissible loading kg/ha - baseline (kg/ha) = allowable addition kg/ha: Maintain EC below 2 mS/cm.

[4] EC x 640 (for NaCl system) = mg/l or ppm.
850

[5] $SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$ (ions in meq/l), consider equal amounts of Ca and Mg here.

[6] Gypsum recommended to reduce SAR, however, land spreading is not recommended due to the large area required.

APPENDIX C5. WASTE DISPOSAL SCENARIOS (Continued)

tolerable provided surface soil structure, consistence and tilth are not significantly degraded. Spread rate calculations are based on texture, moisture content and bulk density of the solids. The solids do not only consist of pure clay but sands, carbonates, etc. Organics are a big "black box". Taking some simple mud inputs of organic compounds the organics add up to substantial amounts to be disposed. Research is urgently needed to study physical, chemical and microbiological effects on soil, possible phytotoxic effects on plants and production of possibly toxic decomposition products.

2. KCl Sumps/Muds

Major limiting factors of concern are potassium, chloride and sulphate ions together with trace metals and organics. Even though potassium, chloride and sulphate are beneficial to plant growth when added in the right amounts, the volumes and concentrations often exceed these limits and would require an unreasonably large area for disposal. Nickel seems to be the most limiting trace element. The sumps would have to be treated to tolerable levels or injected into disposal wells. Organics are again the big unknown: the same restrictions hold as for Freshwater Muds.

3. NaCl Sumps/Muds (Appendix Table C3)

Without reducing the concentrations of sodium, chloride and sulphate, sodium chloride sumps are, practically, not disposable by surface spreading. Trace elements, especially chromium, are also of potential concern. Organics and especially biocides to be disposed increase with increasing volumes. The same restrictions hold as for the Freshwater sumps.

4. Invert Sumps/Muds

An example calculation for invert mud sumps was not attempted because of too many unknowns. Factors to be considered for disposal are oil associated with solids, biocides, organics, clays and salts.

5. General Observations

Even though based on many assumptions the example calculations show that disposal of sump fluids is difficult to generalize. For the examples given, only a Luvisolic soil was considered. Spread rates would have to change for different soil types. Surface spreading on Gleysolic or Organic soils is not feasible. Amounts spread could be increased, and the area needed consequently reduced, if more than 20 cm incorporation depth or leaching would be taken into account. Apart from soil considerations, however, monitoring of possible leaching into groundwater would be necessary if higher spread rates were used. The best and safest approach would be calculation of spread rates based on sump and site/soil parameters. This could be done in co-operation with operators and the surveillance agency; an approach which is currently practiced in Michigan (Crabtree, 1985). Major parameters to be considered for freshwater sumps are chloride, sulphate and trace element content, as well as physical properties. Organics are also a concern. Major limiting constituents in KCl sumps are salts (K, Cl, SO4), trace elements and organics. For NaCl sumps, limiting constituents are similar to the KCl sumps (Na, Cl, SO4, trace elements and organics) but the magnitude of the salt problem appears to be higher. Limiting constituents in invert mud sumps have been pointed out but are difficult to quantify.

The effect of organics is currently accounted for by the trout test or microtox test. These bioassays are not specifically geared towards plant toxicity, but at least indicate possible general effects. Specific research on organics is urgently needed.

Appendix Table C4. Surface Water Quality Objectives.

These objectives represent water quality suitable for most uses either through direct use or prepared for use by an economically practical degree of treatment. They apply to surface waters except in areas of close proximity to outfalls.

There are many instances where the natural water quality of a lake or river does not meet some of the suggested limits. In these cases, the limits obviously will not apply. It should be noted, however, that where the natural existing quality is inferior to desirable criteria, it would be unwise to permit further deterioration by unlimited or uncontrolled introduction of pollutants. Naturally occurring circumstances are not taken into account in these objectives and due consideration must be given where applicable (e.g. spring runoff effect on colour, odour, etc.).(8)

1. Bacteriology (Coliform Group)

   (a) In waters to be withdrawn for treatment and distribution as a potable supply or used for outdoor recreation other than direct contact, at least 90 per cent of the samples (not less than five samples in any consecutive 30-day period) should have a total coliform density of less than 5,000 per 100 ml and a fecal coliform density of less than 1,000 per 100 ml.

   (b) In waters used for direct contact recreation or vegetable crop irrigation the geometric mean of not less than five samples taken over not more than a 30-day period should not exceed 1,000 per 100 ml total coliforms, nor 200 per 100 ml fecal coliforms, nor exceed these numbers in more than 20 per cent of the samples examined during any month, nor exceed 2,400 per 100 ml total coliforms on any day.

2. Dissolved Oxygen

   A minimum of five mg/l at any time.

3. Biochemical Oxygen Demand

   Dependent on the assimilative capacity of the receiving water, the BOD must not exceed a limit which would create a dissolved oxygen content of less than five mg/l.

4. Suspended Solids

   Not to be increased by more than 10 mg/l over background value.

5. pH

   To be in the range of 6.5 to 8.5 pH units but not altered by more than 0.5 pH units from background value.

6. Temperature

   Not to be increased by more than 3°C above ambient water temperature.

7. Odour

   The cold (20°C) threshold odour number not to exceed eight.

8. Colour

   Not to be increased more than 30 colour units above natural value.

9. Turbidity

   Not to exceed more than 25 Jackson units over natural turbidity.

Appendix Table C4. Surface Water Quality Objectives (Continued).

10. Organic Chemicals

Constituent	Maximum Concentration (mg/l)
Carbon Chloroform Extract (CCE) (includes Carbon Alcohol Extract)	0.2
Methyl Mercaptan	0.05
Methylene Blue Active Substances	0.5
Oil and Grease	substantially absent, no irridescent sheen
Phenolics	0.005
Resin Acids	0.1

11. Pesticides

To provide reasonably safe concentrations of these materials in receiving waters an application shall not exceed 1/100 of the 48-hour Tl_m. No pesticides can be used in Alberta unless they have been registered under the Pest Control Products Act. Any pesticides used on, in, or near water (within 100 linear feet) must be approved by a Department of Environment permit issued under The Agricultural Chemicals Act.

12. Toxic Chemicals

Constituent	Maximum Concentration (mg/l)
Arsenic	0.01
Barium	1.0
Cadmium	0.01
Chromium	0.05
Cyanide	0.01
Lead	0.05
Mercury	0.0001
Selenium	0.01
Silver	0.05

13. Radioactivity

Gross Beta not to exceed 1,000 pCi/l.
Radium 226 not to exceed three pCi/l.
Strontium 90 not to exceed 10 pCi/l.

14. Inorganic Chemicals

Constituent	Maximum Concentration (mg/l)
Boron	0.5
Copper	0.02
Fluoride	1.5
Iron	0.3
Manganese	0.05
Nitrogen (Total Inorganic and Organic)	1.0
Phosphorus as PO_4 (Total Inorganic and Organic) ...	0.15
Sodium (as percent of cations)	between 30 & 75
Sulphide	0.05
Zinc	0.05

NOTE: The predominant cations of SODIUM, CALCIUM and MAGNESIUM and anions of SULPHATE, CHLORIDE and BICARBONATE are too variable in the natural water quality state to attempt to define limits. Nevertheless, in order to prevent impairment of water quality, where effluents containing these ions are discharged to a water body the permissible concentration will be determined by the administrative authority in accordance with existing quality and use.

15. Unspecified Substances

Substances not specified herein should not exceed values which are considered to be deleterious for the most critical use as established by the administrative authority.

Appendix Table C5. Summary of Recommended Groundwater Limits.

Parameter	Maximum Acceptable Concentration*	Objective Concentration*	Basis**
Aldrin + Dieldrin	0.0007	$\leq 5 \times 10^{-8}$	H
Antimony	—	≤ 0.0002	H
Arsenic	0.05	≤ 0.005	H
Asbestos	—	—	—
Barium	1.0	≤ 0.1	H
Boron	5.0	≤ 0.01	H
Cadmium	0.005	≤ 0.001	H
Carbaryl	0.07	$\leq 5 \times 10^{-4}$	H
Chlordane (Total)	0.007	$\leq 5 \times 10^{-8}$	H
Chloride	250	<250	A
Chromium	0.05	≤ 0.0002	H
Colour (TCU)	15	<15	A
Copper	1.0	<1.0	A
Cyanide	0.2	≤ 0.002	H
DDT (Total)	0.03	$\leq 5 \times 10^{-8}$	H
Diazinon	0.014	$\leq 1 \times 10^{-6}$	H
Dieldrin + Aldrin	0.0007	$\leq 5 \times 10^{-8}$	H
Endrin	0.0002	$\leq 5 \times 10^{-8}$	H
Fluoride	1.5	1.0***	H & A
Hardness	—	—	—
Heptachlor + Heptachlor Epoxide	0.003	$\leq 5 \times 10^{-8}$	H
Iron	0.3	<0.05	A
Lead	0.05	≤ 0.001	H
Lindane	0.004	$\leq 1 \times 10^{-7}$	H
Manganese	0.05	<0.01	A
Mercury	0.001	≤ 0.0002	H
Methoxychlor	0.1	$\leq 5 \times 10^{-8}$	H
Methyl Parathion	0.007	$\leq 1 \times 10^{-6}$	H
Nitrate (as N)	10.0	≤ 0.001	H
Nitrilotriacetic Acid (NTA)	0.05	≤ 0.0002	H
Nitrite (as N)	1.0	≤ 0.001	H
Odour	—	Inoffensive	A
Parathion	0.035	$\leq 1 \times 10^{-8}$	H
Pesticides (Total)****	0.1	—	H
pH	6.5 – 8.5	—	A
Phenols	0.002	<0.002	A
Selenium	0.01	≤ 0.002	H
Silver	0.05	≤ 0.005	H
Sodium	—	—	—
Sulphate	500	<150	H & A
Sulphide (as H_2S)	0.05	<0.05	A
Taste	—	Inoffensive	A
Temperature (°C)	15	<15	A
Total Dissolved Solids	500	—	A
Total Organic Carbon	—	—	—
Toxaphene	0.005	$\leq 5 \times 10^{-8}$	A
Trihalomethanes	0.35	≤ 0.0005	H
Turbidity (NTU)	5	<1	H & A
Uranium	0.02	≤ 0.001	H
Zinc	5.0	<5.0	A
2, 4-D	0.1	≤ 0.001	H
2, 4, 5-TP	0.01	≤ 0.001	H

* Unless indicated otherwise, the maximum acceptable and objective concentrations are specified in mg/L.

** Maximum acceptable and objective concentrations have been established on the basis of either aesthetic (A) or health (H) considerations.

*** In areas where the annual mean maximum temperature is below 10°C, the objective is 1.2 mg/L.

**** The "total pesticides" limit applies to water in which more than one of the pesticides listed in this Table is present, in which case, the sum of their concentrations should not exceed 0.1 mg/l

Source: Guidelines for Canadian Drinking Water Quality, 1978.

APPENDIX D

EXISTING ALBERTA GUIDELINES

Appendix D1.

APPENDIX I

TO INTERIM DIRECTIVE NO. ID-OG 75-2

SUMP FLUID DISPOSAL REQUIREMENTS

1.0. Disposal of Sump Fluids to a Subsurface Formation

Disposal of sump fluids to a subsurface formation is an acceptable procedure provided:

a. Approval is first obtained from the Energy Resources Conservation Board.

b. The subsurface formation is not locally productive of oil or gas.

c. The formation water in the disposal zone has a total dissolved solids content greater than 20,000 mg/l.

2.0 Disposal of Sump Fluids on the Lease

Disposal of sump fluids to the lease is an acceptable procedure providing all of the following conditions are met:

a. Notice of at least one week has been given to:

   i. the appropriate District Office of Alberta Energy and Natural Resources if the well was drilled on any public land in the province.

   ii. the appropriate Area Office of the Energy Resources Conservation Board if the well was drilled on any other lands not specified in section 2.0 (a).

b. The entire contents of the sump are confined to the lease.

c. The sump(s) contain less than a total of 6,000 barrels of fluid. Not withstanding this limitation, approval may be given by the Board or Alberta Energy and Natural Resources to dispose of more than 6,000 barrels of fluid to the lease providing it can be shown that the entire contents of the sump will be confined to the site. Applications for such approval shall be directed, in the appropriate case, to either the Area Office of the Energy Resources Conservation Board or District Office of Alberta Energy and Natural Resources.

d. The lease is more than 300 feet from the normal high water mark of a body of water, permanent stream or potable water well.

e. The lease site will, in the opinion of the Energy Resources Conservation Board or Alberta Energy and Natural Resources, accept the sump contents, to be disposed, without run-off.

3.0 Disposal of Sump Fluids off the Lease

3.1 Disposal of sump fluids to off-lease land areas is an acceptable procedure providing:

a. The sump fluids meet the following criteria:

Chloride Content	1000 mg/l Maximum
Sulfate Content	2000 mg/l Maximum
Total Dissolved Solids	4000 mg/l Maximum
pH	5.5 to 8.5
Trout Survival Test	96 Hrs. (see Appendix "B" - Guidelines Used to Determine Fish Toxicity Tests on Sump Fluids).

b. Approval to dispose off the lease has been obtained in accordance with section 3.3.

3.2 The Energy Resources Conservation Board or Alberta Energy and Natural Resources will consider off-lease disposal which is not according to the criteria outlined in section 3.1. Application shall be made in the appropriate case, to the Area Office of the Energy Resources Conservation Board or the District Office of Alberta Energy and Natural Resources.

3.3 Off-Lease Disposal Approval

3.31 On public lands throughout the Province, disposal of well sump fluids to land off the lease and the location of the disposal site must be approved by the appropriate District Office of Alberta Energy and Natural Resources.

3.32 On all land not described under subsection 3.31, disposal of well sump fluids to land off the lease must be approved by the Energy Resources Conservation Board, subject to the disposal and disposal site having been approved by the landowner.

3.33 Any licensee of a well who intends to dispose of fluids to land off the lease area shall:

a. sample the fluids according to the procedure outlined in Appendix A.

b. analyze and field-treat the sump fluids so that the fluid to be disposed of meets the criteria outlined in section 3.1. Tests must conform to the guidelines outlined in Appendix B.

c. two days prior to treating the fluids and depending on whether the lease is located on public or other lands, notify, in the appropriate case, the District Office of Alberta Energy and Natural Resources or the Area Office of the Energy Resources Conservation Board.

3.34 The request for approval to dispose of sump fluids to land off the lease area must be submitted, in the appropriate case, to the District Office of Alberta Energy and Natural Resources or the Area Office of the Energy Resources Conservation Board, and contain the following information:

a. a description of the sampling procedure.

b. a general description of the method of treatment of the sump fluids.

c. an analysis of a representative sample of the treated sump fluids (including trout survival test).

d. the location of the disposal area and the volume of sump fluids to be disposed of.

e. a brief description of the surrounding area (i.e., whether it is forested, muskeg, swamp and the kind of vegetation present).

f. in the case of disposal to private lands, a statement that the landowner's permission has been obtained to dispose to the off-lease site.

3.4 Disposal of well sump fluids to any surface water either directly or indirectly by land surface drainage must be approved by Alberta Environment. Only under rare circumstances, and where sufficient lease land or peripheral land disposal sites are not available, is such disposal considered.

APPENDIX A

GUIDELINES FOR OBTAINING A REPRESENTATIVE SAMPLE OF THE SUMP FLUIDS

1. Divide the sump into six segments and then obtain samples near the surface, middle and bottom of each segment. In this way 18 samples will be obtained to form a single composite sample.

2. The minimum composite sample size is 2 quarts collected in a glass or plastic container.

3. The sample should be submitted for analysis to a reliable commercial laboratory.

APPENDIX B

GUIDELINES USED TO DETERMINE FISH TOXICITY TESTS ON SUMP FLUIDS

Drilling sump fluids may contain a variety of complex organic and inorganic compounds, the combined effects of which are difficult to ascertain. Therefore, the fish survival test is being used as a part of the criteria to evaluate the toxicity of treated sump fluids.

The person carrying out the test may be reasonably certain that if any fish survives the 96 hour test the treated sump fluids are minimally toxic. However, if both fish die within a very short period of exposure to the treated sump fluids, then further treatment of the fluids is necessary. In cases where it appears that problems are being experienced with fluid detoxification, the Board's Chief Chemist should be consulted.

Requirements of the standard bioassay tests apply as stated in the latest edition of Standard Test Methods[1] except for those points mentioned below:

1. The test fish to be used are small trout fingerlings 4 to 10 centimetres in length, which have been living in standard dilution water[2].
2. Two fish are to be used per test.
3. Test fish are not to be used for more than one test during their lifetime.
4. A minimum of 1 litre of the test water is required.
5. The test water container is to be of glass and of a minimum capacity of approximately 2 litres.
6. A control test is to be carried out (using standard dilution water) simultaneously with the actual sump fluid test.
7. Dissolved oxygen in the control and test jars is to be maintained at a minimum of 8 mg/litre.

---

[1] Standard methods for the examination of water and waste water. Thirteenth edition 1971, APAJ, AWWA, WPCF. American Public Health Association, 1015 - 18 St. N. W., Washington, D. C. 20036.

[2] Standard dilution water:

For every 10 imperial gallons of demineralized water, add the following reagent grade chemicals:

1. 4 grams $CaSO_4 \cdot 2H_2O$
2. 4 grams $MgSO_4 \cdot 7H_2O$
3. 1.5 grams $CaCl_2 \cdot 2H_2O$
4. 3.0 grams $NaHCO_3$
5. .2 grams KCl
6. .125 grams $Ca(OH)_2$
7. .125 grams $Mg(OH)_2$

APPENDIX II

Interim Directive ID 81-1

ENERGY RESOURCES CONSERVATION BOARD
Calgary Alberta

TO: ALL OIL AND GAS OPERATORS

SUBSURFACE DISPOSAL OF DRILLING FLUIDS

This Interim Directive supersedes Interim Directive ID 70-3 issued on 15 December 1970.

The Board will permit operators to dispose of drilling fluids not only in dry holes but to any well where subsurface disposal of drilling fluids is feasible.

The Board believes that under appropriate constraints the subsurface disposal of drilling fluids can be carried out without jeopardizing any subsurface potable water horizons. It will consider such disposal as part of the drilling or completion program for a well and separate approval under section 38 of The Oil and Gas conservation Act will not be required. The subsurface disposal of drilling fluids may be carried out subject to the following conditions.

1. Permission of a Board representative shall be obtained before any disposal operation is commenced.
2. The disposal zone shall be at a depth not less than 600 metres.
3. The resistivity directly attributable to the total natural dissolved solids in the FORMATION WATER of the disposal zone shall be less than 0.33 OHM.M corrected to 20°C (equivalent to 20,000 ppm total dissolved solids).
4. The disposal zone shall be known not to contain hydrocarbons within 2 kilometres of the intended disposal well.
5. Where a well is to be abandoned or plugged back and does not contain at least 600 metres of casing cemented in place:
    a. the disposal of fluids shall be through drill pipe and below a seated packer, and
    b. the annulus between the drill pipe and the surface casing shall remain open to the atmosphere during any disposal operation.

6. Where a second casing string has been run in a well and not cemented to surface:

   a. the disposal of fluids shall be through the annulus between the casings, provided the surface casing is deeper than 600 metres,

   b. the disposal zone shall be identified by depth and geological designation,

   c. the fluids to be disposed shall be displaced out of the annulus with a corrosion inhibited fluid. If, after displacement, pressure exists in the annulus, cement shall be displaced into the formation to seal off the disposal interval, and

   d. the annulus shall be left open to the atmosphere in the manner described in subsection 6.100(2) of the Oil and Gas Conservation Regulations.

7. Where the disposal zone has been cemented behind casing:

   a. the disposal zone shall be identified by depth and geological designation.

   b. the casing shall be perforated and the fluids disposed of through the perforations, and

   c. the perforations shall be appropriately sealed or isolated.

ISSUED at Calgary, Alberta, on 12 March 1981.

ENERGY RESOURCES CONSERVATION BOARD

Appendix D3.

GUIDELINES FOR SUMP FLUID DISPOSAL ON CROWN LAND
WHITE AND YELLOW AREAS

Filing and Recording

All correspondence with regards to sump fluids should be kept in the same filing system as the mineral surface lease (MSL) for convenience and reference during inspections.

A ledger or card system may be kept for quick reference to assist office staff when inspectors have the files in the field. This ledger should be designed to record key aspects of sump management. Attached example used by A.F.S..

Notification

The Energy Resources Conservation Board (E.R.C.B.) issued a bulletin notifying industry that Public Lands District Offices are responsible for sump fluid disposal effective September 1, 1983 in the white and yellow areas. In addition to this directive, Head Office in Edmonton will include as an operating condition in any letter of authority that a written request for sump fluid disposal (either on or off lease) must be directed to the Surface Reclamation Officer, Public Lands Division District Office. The Public Lands District Office is to be notified one week prior to the commencement of sump disposal.

Application

Upon receipt of an application for disposal from the company, the Public Lands District Office should review it carefully to ensure chemical and fish bio-assay results are in accordance with E.R.C.B. guidelines (ID-OG-75-2).

This request must contain the following information:

1. The number of barrels of fluid to be disposed of.
2. Chemical analysis of fluids and fish bio Assay Result when over 6,000 bbl.
3. An attached written approval from the land occupant where applicable.
4. A sketch of written explanation of the disposal area, and an explanation of the disposal method.
5. Tentative date that the disposal may be carried out and an explanation of arrangements to advise the Public Lands Division office of the exact date the disposal will take place.

A reply should be generated to the company in less than one week. Use your own discretion in giving verbal approval in situations where a company requests immediate approval to dispose of sump fluids. This should always be followed up in writing.

When the company comes into your office requesting approval for sump fluid disposal have the company complete "Example Form A" for on lease and off lease disposal. Record date the application is received requesting approval.

Letter to Company

Use "example Form B" as an approval letter for off lease disposal and "example Form C" as an approval letter for on lease disposal. Record date letter of approval issued.

Method of Disposal - see ID-OG 75-2

The three acceptable disposal methods are as follows:

(a) Disposal of Sump Fluids to a Subsurface Formation -

Must be referred to E.R.C.B. for processing.

(b) Disposal of Sump Fluids On the Lease -

Approval must be obtained from E.N.R. for disposal on lease even if quantity is under 6,000 bbls. While the E.R.C.B. regulations do not require the under 6,000 bbl sumps to be treated prior to on-lease disposal, the Public Lands Officer may delay disposal until he is satisfied that the lease can physically and chemically accept the fluids without damage.

Approval may be given for on lease disposal if the sump contains more than 6,000 bbls and the lease area is capable of handling the fluids. The disposal must meet the chemical criteria for off lease disposal. The operator must be advised (and confirmed in writing) that sump fluids must be treated as though off lease disposal will take place. It is very important that the lease be dyked to contain the sump fluids disposed of on the lease in order to contain them, especially if there is little usable space on the lease. Allowing the sump fluids to escape the lease is in contravention of Section 8.150 of the Oil and Gas Conservation Regulations. The Public Lands Officer should remind the operator that adequate precautions must be taken to ensure the containment of sump fluids on the lease.

(c) Disposal of Sump Fluids Off the Lease -

Company must have an analysis of the sump. The chemical concentration must be less than or equal to the following:

Chlorides:	1,000 mg/l
Sulphates:	2,000 mg/l
Total Dissolved Solids:	4,000 mg/l
pH:	5.5 - 8.5
Trout Bio-Assay:	Nil mortality rate for 96 hours

Off Lease Application

District offices should monitor off lease disposal in the following manner:

(a) A careful review and assessment of the application.

(b) Selective witnessing of actual treatment.

(c) Selective sampling of the treated sump fluids to confirm the effectiveness of the treatment through field tests or by analysis in E.R.C.B.'s Chemical Laboratory.

(d) Selective witnessing of the disposal of the fluids to ensure that they are disposed of to the approved location and are spread over an appropriate area in a manner such that erosion or other problems do not arise.

(e) Follow-up inspection of the disposal area to assess possible environmental effects.

In the initial stages of administering sump fluid disposal you may wish to sample and witness a large number of sump fluids as time permits to be able to effectively assess industry's performance.

Upon becoming familiar with the process and getting to know the individual companies a 10% sample of all sumps in your district should be adequate.

Check Sample

Direction will be given for procedure in submitting samples.

Record the date the check sample was taken. A sample of the untreated sump fluid should be taken only when the operator will be disposing sump fluids off the lease. Such samples should be obtained in the same manner as outlined in E.R.C.B.'s Interim Directive ID-OG-75-2 Appendix A. As it is impractical to obtain samples of fluids from all sumps that are to be disposed of off lease, the Public Lands Officer should judge what samples should be taken on the basis of the operators past reliability, and the service companies he is employing, or because a number of treatments were required to bring the sump fluids within the specifications for disposal. A 2 litre sample is required and should be taken at a depth of 1 - 1.5 feet in a well mixed sump, or from the pump off of a treated sump. Prior to collecting any sample the fluids should have been thoroughly mixed so a representative sample is obtained. Field checks (pH test and Quantab test for chlorides, etc.) may be employed to give an indication of the reliability of the analytical information previously provided by the operator. This check may result in the suspension of sump disposal operation until such time as a "grab sample" can be analyzed.

Treatment

Two days prior to treating the fluids, when the lease in on public lands the company is to notify the District Office of Alberta Energy and Natural Resources. Sampling prior to treatment and during treatment is the responsibility of the operator and should be carried out by a commercial laboratory.

Enforcement

The Board's Legislative backing for enforcement of the "Well Sump Fluid Treatment and Disposal Requirements" are Sections 8.150 and 8.160 of the Oil and Gas Conservation Regulations.

Contravention of the Regulations can be dealt with in the following manner:

(A) Hold a meeting with supervisory personnel representing the company that committed the offense to express our concern and attempt to bring the operator in line. Results of such meetings should be confirmed in writing.

(B) At the request of Alberta Energy and Natural Resources or on its own initiative, the Board may call an inquiry to investigate the circumstances leading to the offense, and as a result of the inquiry may order that approved methods are adapted or that appropriate remedial measures are taken to correct the situation.

(C) Initiate a prosecution.

General Information

Chlorides above 1,000 mg/l cannot be treated out therefore they have to be spaced over a larger area to reduce the effective concentration. The formula used to calculate the number of acres required is:

$$\frac{\text{Cl} \times 350 \times \text{No. of bbls}}{400{,}000{,}000} = \text{Acres}$$

ex. 12,000 bbl sump with 3,000 mg/l of chloride

$$\frac{3{,}000 \times 350 \times 12{,}000}{400{,}000{,}000} = 31.5 \text{ acres}$$

Chlorides spread rate max. of 400 lbs./acre on a good chernozem soil. Sulfates between 2,000 - 3,000 mg/l a rule of thumb is to simply dispose of them at a rate of 500 bbl/acre. Both rates must be adjusted downwards for poorer soils.

If the total dissolved solids are high, it is usually because the chlorides or sulphate contents are high. The formula for chloride disposal shown above is normally acceptable for spreading the solids. If chlorides or sulphates are not high in content the sump fluid should be flocculated more to reduce the total dissolved solids.

Cardboard Shipping Boxes

SHIPPERS SUPPLY
5215 - 82 Avenue
Edmonton, Alberta
T6B 2J6

Ph. 465-0927

2 bottles per box
5"" x 8" x 10"

Wooden cases can be made up locally which will last much longer.

Due to economic restraint it is suggested that a sturdy box be located locally for shipment of samples. The sample bottles are to be insulated during packaging to prevent damage. It is advisable to tape the lids as they are prone to leaking.

Sump Volume and Lease Capacity

A) Sump Volume (Approximate Volume)

$$\text{Sump Volume (ft.}^3\text{)} = \frac{\text{Length}}{2} \times \text{Width} \times \text{Depth}$$

$$\text{Sump Volume (bbls)} = \frac{\text{Sump Volume (ft.}^3\text{)}}{5.61\ \text{(bbls/ft.}^3\text{)}}$$

1 bbl. = 5.6 cu. ft.

B) Lease Capacity

1 Acre = 660 feet x 66 feet or 43,560 sq. ft.

i.e. A 4 acre lease has a sump 400 long, 20' wide, and 10' deep Volume of the Sump is 40,000 ft.^{3} or 7,130 barrels.

1) The sump fluids if spread over the entire 4 acre lease would leave 2.6 inches of water and mud over the lease. Spread thickness (in.)

$$= \frac{\text{Sump Volume ft.}^3}{\text{Lease Area ft.}^2} \times 12"$$

$$= \frac{40{,}000 \text{ ft.}^3}{174{,}\ 240 \text{ ft.}^2} \times 12"$$

2) The sump fluids if spread on 2 acres of usable space on the lease, would result in 5.4 inches of water and mud over the entire lease.

$$= \frac{40{,}000 \text{ ft.}^3}{87{,}120 \text{ ft.}^2} \times 12"$$

$$= 5.4 \text{ inches}$$

Infiltration rate approximately = .1" per hour.

*It is very important that the lease by dyked to contain the sump fluids disposed of on the lease in order to contain them, especially if there is little usable space on the lease for this method of disposal.

Appendix D4.

APPENDIX III

ENERGY AND NATURAL RESOURCES
INFORMATION LETTER 82-5

SUBJECT: Potassium-Based Drilling Mud Systems

In recent years some companies have chosen to use potassium-based drilling mud systems in special situations, particularly on the deeper wells being drilled in the Eastern Slopes Region of Alberta. The result has been large accumulation of fluids which represent a disposal problem because of their toxicity to aquatic life and to vegetation. No method currently exists to remove the potassium component.

Problems can be minimized if disposal is planned by the lessee prior to the commencement of drilling. An option that should receive special attention is contained in the Energy Resources Conservation Board's Interim Directive 1D-81-1 of March 12, 1981, Subsurface Disposal of Drilling Fluids.

Commencing immediately, lessees of public lands who plan to use potassium-based drilling mud systems will be required to submit a plan for disposal of the fluids resulting from the drilling operation. Plan approval must be obtained from the field office of the Department designated in the surface lease conditions prior to the commencement of lease construction.

Further information may be obtained from the following persons:

Public Lands Inside the Green Area

Mr. W.N. Barnes,
Forest Land Use Branch,
Alberta Forest Service,
Alberta Energy and Natural
Resources
Petroleum Plaza, South Tower,
9915 - 108 Street
Edmonton, Alberta,
T5K 2C9
Telephone (403) 427-3587.

Public Lands Outside the Green Area

Mr. K.M. Lyseng,
Land Management and Development
Branch,
Public Lands Division,
Alberta Energy and Natural
Resources,
Petroleum Plaza, South Tower,
9915 - 108 Street,
Edmonton, Alberta,
T5K 2C9
Telephone: (403) 427-5209.

Care of Well Sites and Battery Sites

8.150 (1) In this section, "liquid waste" means drilling fluids, oily waste or other liquid products from a well, battery or other production installation.

(2) The licensee of a well or operator of a battery shall ensure that liquid waste is contained at all times, and

(a) dispose of, or cause to be disposed of, all liquid waste on the well or battery site in such a manner that no air, soil, surface water or underground source of potable water is or could be polluted, or

(b) where liquid waste is removed from the well or battery site, dispose of such liquid waste in a manner approved,

(i) if the disposal site is on public lands, by the Minister of Energy and Natural Resources, or

(ii) if the disposal site is not on public lands, by the Board.

(3) An earthen pit at a well site used to store liquid wastes from a drilling or servicing operation shall

(a) be excavated to a depth to which it may be filled with liquid, and

(b) be so located and constructed that it will not collect natural run-off water.

(4) Where the surface topography is such that a satisfactory storage pit of sufficient capacity cannot be constructed, the licensee of a well or operator of a battery shall contain all liquid waste in tanks and shall remove such liquid waste without undue delay to an area approved under subsection (2) clause (b).

(5) Upon the completion, suspension or abandonment of a well or the abandonment of a battery, the licensee of the well or operator of the battery shall

(a) dispose of all liquid waste,

(b) clear the area of debris,

(c) fill all excavations made in connection with the well or battery, and

(d) advise the appropriate Board Area Office when the operation is completed.

(6) The licensee of a well or the operator of a battery shall maintain the well or battery site in a clean condition.

(7) If the Board is satisfied that such disposal methods will not pollute air, soil or potable water sources it may, upon application, approve other disposal methods instead of those prescribed by this section.

(AR 151/71; AR 241/71; AR 69/72; AR 51/81)

8.160 (1) In this section "waste material" means water, rubbish, debris, drilling fluids, oil, oil waste, sand tailings or other products from a well, oil sands operation, tank or other production installation.

(2) The licensee of a well or operator of a battery or scheme shall

(a) ensure that waste material is contained at all times,

(b) dispose of, or cause to be disposed of, all waste material in such a manner that no soil, surface water or underground source of potable water is or could be polluted, and

(c) ensure that waste material does not

(i) create or constitute a safety hazard or nuisance or,

(ii) run over or damage any soil, highway or public road.

(3) Waste material may be moved from the well site or battery site to a place where it may be disposed of without causing soil or water pollution with the approval,

(a) if the place of disposal is on public lands, of the Minister of Lands and Forests, or

(b) if the place of disposal is not on public lands, of the Board.

(AR 151/71; AR 69/72)

Fencing

8.170 (1) At each battery at which the hydrogen sulphide concentration in a representative sample of the gas from any well producing to the battery is found to exceed 10 moles per kilomole, or such high or lower ratio as the Board may by order stipulate in a particular case, the licensee shall construct and maintain an adequate fence around the battery, but the Board, on application, may exempt a battery from the provisions of this section where it is of the opinion that the pressures, nature of production, remoteness of area or other circumstances warrant the exemption.

(2) For the purpose of subsection (1) a fence shall be considered adequate if,

APPENDIX E

INFORMATION GATHERING THROUGH KEY CONTACTS AND LITERATURE SEARCHES

Appendix E1. List of Individuals/Agencies Contacted

1. PUBLIC LANDS DIVISION

Key Contact: Mr. D.A. Lloyd
Public Lands Division
Land Management and Development Branch
9915 - 108 Street, 4th Floor
Edmonton, Alberta
T5K 2C9
Tel. 428-5209 or 437-4418

Jeff Hartley
Room 3001, Box 34
Provincial Building
10320 - 99 Street
Grande Prairie, Alberta
Tel. 538-5260

Brian Kremeniuk
Box 280
Provincial Building
Bonnyville, Alberta
T0A 0L0
Tel. 826-4297

Barry Cole
405, 4901 - 48 Street
Parkland Square
Red Deer, Alberta
T4N 5Y5
Tel. 340-5451

2. ALBERTA FOREST SERVICE

Neil Barnes
Technical Development
Forest Land Use Branch
9920 - 108 Street
Edmonton, Alberta
T5K 2M4
Tel. 427-3583

Glenn MacPherson
Forest Officer
General Delivery
La Corrie, Alberta

Gordon Krassman
Forest Land Use Officer
Rocky/Clearwater Forest
Box 1720
Rocky Mountain House, Alberta
T0M 1T0
Tel. 845-3365

Bruce McGregor
Forest Land Use Officer
Slave Lake Forest
Slave Lake, Alberta
T0G 2A0
Tel. 849-3061

3. ERCB

Don R. Shaw
Chief Chemist
ERCB Research Lab
3512 - 33 Street, N.W.
Calgary, Alberta
T2L 2A6
Tel. 297-2447

Ivan Weleschuk
640 - 5th Avenue S.W.
Calgary, Alberta
T2P 3G4
Tel. 297-8448

4. ENVIRONMENT

Dr. C. Palmer
Section Head
Soil Chemistry & Physics
Technical Development Branch
3rd Floor, Cousins Building
Lethbridge, Alberta
T1J 4B3
Tel. 329-5322

Nancy Finlayson
Alberta Environment
Land Reclamation Division
3rd Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta
T5R 2J6
Tel. 427-6212

Appendix E2. Literature Searches

Information was gathered by searching card catalogues, microfiche and computerized data bases of the following libraries:

1. Alberta Energy and Natural Resources, Edmonton
2. Alberta Environment, Edmonton
3. Alberta Research Council, Edmonton
4. Arctic Petroleum Operators Association, Calgary
5. Canadian Petroleum Association, Calgary
6. Energy Resources Conservation Board, Calgary
7. Independent Petroleum Geologists Association of Canada, Calgary
8. University of Alberta, Edmonton
9. University of Calgary, Calgary

APPENDIX F

GLOSSARY

APPENDIX F

GLOSSARY

Absorption: The process by which a substance is taken into and included within another substance, i.e. intake of water by soil, or intake of gases, water, nutrients, or other substances by plants.

Adsorption: The process by which atoms, molecules, or ions are taken up and retained on the surfaces of solids by chemical or physical binding, e.g. the adsorption of cations by negatively charged minerals.

Advection: is transportation by the bulk or macroscopic motion of the flowing groundwater and is the single most important transport mechanism of groundwater. Through this process, non-reactive contaminants move at an average rate known as the average linear velocity v:

$$v = \frac{v}{n}$$

where: v = Darcy's velocity
n = effective porosity

The effective porosity is the total volume of interconnected voids in the material through which the groundwater flows. Values of effective porosity (n) are typically less than 0.35 (Todd, 1959).

Aerobic: Having molecular oxygen as a part of the environment. Growing only in the presence of molecular oxygen, as aerobic organisms. Occurring only in the presence of molecular oxygen (said of certain chemical or biochemical processes such as aerobic decomposition).

Anaerobic: The absence of molecular oxygen. Growing in the absence of molecular oxygen (such as anaerobic bacteria) occurring in the absence of molecular oxygen (as a biochemical process).

Aquifer: Stratum or zone below the surface of the earth capable of producing water as from a well.

Aquitard: Stratum and zone below the surface of the earth which contains but cannot transmit water, e.g. clay.

Available Nutrients: Nutrient ions or compounds in forms which plants can absorb and utilize in growth.

Available Water: The portion of water in a soil that can be absorbed by plant roots.

Buffering Capacity: Capacity of a soil to resist appreciable pH change in the soil solution.

Bulk Density: the ratio of the mass of water-free soil to its bulk volume. Bulk density is expressed in pounds per cubic foot or grams per cubic centimeter and is sometimes referred to as "apparent density". When expressed in grams per cubic centimeter, bulk density is numerically equal to apparent specific gravity or volume weight.

Buried Valley Aquifer: Sands and gravels which were deposited in broad valleys by rivers draining eastward from the Rocky Mountains prior and occasionally during glaciation. During glaciation the valleys were covered with till and other glacial drift.

Cation Exchange: The interchange of a cation in solution with another cation on a surface-active material.

Cation-Exchange-Capacity: The total quantity of cations which a soil can absorb by cation exchange, usually expressed as milliequivalents per 100 grams. Measured values of cation-exchange-capacity depend somewhat on the method used for the determination.

Cretaceous: Geological time; third and latest period of the Mesozoic Era.

Darcy's Law: Law describing the rate of flow of water through porous media (named for Henry Darcy of Paris who formulated it in 1856 from extensive work on the flow of water through sand filter beds).

Devonian: Geological time; fourth in order of age of the periods comprising the Paleozoic Era, following the Silurian and preceding the Mississippian.

Diffusion: The spreading out of molecules, ations, or ions into a vacuum, a fluid or a porous medium, in a direction tending to equalize concentrations in all parts of a system.

Discharge: Discharge of groundwater directly from the zone of saturation upon the land or into a body of surface water.

Dispersed Soil: Soil in which the clay readily forms a colloidal soil Dispersed soils usually have low permeability. They tend to shrink, crack, and become hard on drying and to slake and become plastic on wetting.

Electrical Conductivity (EC): Property of a soil measured from an extract of saturated soil used to describe soil salinity; expressed in millisiemens (mS)/cm at 25°C.

Eolian materials have been transported and deposited by wind action. Associated landforms are dunes and gently undulating plains. Materials consist of medium to very fine sand and are well sorted, well aerated and poorly compacted.

Equivalent; Equivalent Weight: The weight in grams of an ion or compound that combines with or replaces 1 gram of hydrogen. The atomic weight or formula weight divided by its valence.

Exchangeable Cation: A cation that is adsorbed on the exchange complex and which is capable of exchange with other cations.

Exchangeable-Sodium-Percentage: The degree of saturation of the soil exchange complex with sodium. It may be calculated by the formula:

$$\mathrm{ESP} = \frac{\text{Exchangeable sodium (meq./100 gm. soil)}}{\text{Cation-exchange-capcity (meq./100 gm. soil)}} \times 100$$

Fluvial materials have been transported and deposited by streams and rivers in recent or past times. They contain gravel, sand, silt, and a minor fraction of clay. Moderately to well sorted, stratified deposits are most common but massive, non-sorted deposits also occur. Fluvial landforms include floodplains, terraces, upland plains and occasional rolling terrain.

Fluvial-Eolian sediments originate from stream deposits which have been partially reworked by wind. These deposits occur as gently undulating plains with slopes in the 2 to 5% range. Loamy sand to sandy loam textures are most common.

Fluvial-Lacustrine sediments have been deposited by slow-moving water. These deposits are intergrades between the fine sandy to silty fluvial deposits and clayey lacustrine sediments. Slopes less than 5% are most common.

Ground Water: Water in soil beneath the soil surface, usually under conditions where the pressure in the water is greater than the atmospheric pressure, and the soil voids are substantially filled with the water.

Hydraulic Conductivity: Ratio of flow velocity to driving force for viscous flow under saturated conditions of a specified liquid in a porous medium.

Hydraulic Gradient: The decrease in hydraulic head per unit distance in the soil in the direction of the greatest rate of decrease of hydraulic head.

Hydraulic Head: The elevation with respect to a specified reference (level), usually the soil surface, at which water stands in a piezometer connected to the point of question in soil.

Infiltration: The entry of water into soil.

Lacustrine and Lacustro-till materials have settled from suspension in standing fresh water. They are generally fine textured, however, stratified sands, silts and clays also occur. Topography is usually level to undulating.

Leaching: The process of removal of soluble material by the passage of water through soil.

Lime: Strictly, calcium oxide (CaO), but as commonly used in agriculture terminology calcium carbonate ($CaCO_3$) and calcium hydroxide ($Ca(OH)_2$) are included. Agricultural lime refers to any of these compounds, with or without magnesia, used as an amendment for acid soils.

Mechanical dispersion: is a microscopic mixing process caused by the variation in size and shape of the pores (and pore channels) in a media. This process causes the further spreading, both longitudinally and transversely to the direction of groundwater flow, of a contaminant and results in a decline of contaminant concentrations.

Microtox Test: Toxicity Test using bacteria as test organisms which are lypholized (freeze dried under vacuum). AT the time of testing this lypholized bacteria is reconstituted to provide a ready to use cell suspension. The production of light by the organisms reflects their state of health.

Molecular diffusion: is the spreading of contaminants due to differences in concentrations, much the way that the water itself flows from regions of high hydraulic head to regions of low hydraulic head.

Organic deposits or peatlands have formed by accumulation of organic matter due to saturated conditions for prolonged periods. They occur in poorly and very poorly drained depressions and level areas. Peatlands are poorly aerated due to a high water table which results in poor degradation of organic compounds.

Permeability: Soil permeability is that quality of soil that enables it to transmit water and air. Accepted as a measure of this quality is the rate at which soil transmits water while saturated. That rate is the "saturated hydraulic conductivity" of soil physics. In line with conventional usage in the engineering profession and traditional usage in the published soil surveys, this rate of flow, principally downward, continues to be expressed as "permeability".

To rate soil permeability: use the numerical ranges shown below:

	NUMERICAL RANGE		
PERMEABILITY CLASS	inches/hr	cm/hr	mm/hr
Very slow	<0.06	<0.15	<1.5
Slow	0.06-0.2	0.15-0.5	1.5-5
Moderately slow	0.2-0.6	0.5-1.5	5-15
Moderate	0.6-2.0	1.5-5	15-50
Moderately rapid	2.0-6.0	5-15	50-150
Rapid	6.0-20	15-50	150-500
Very rapid	>20	>50	>500

Recharge: Process by which water is absorbed and added to the zone of saturation.

Retardation: is a chemical reaction between reactive constituents carried by the groundwater and the media through which the groundwater flows. In this process the contaminants become, for example, exchanged for other ions, precipitated, or undergo sorption onto the surface, or into, soil or rock particles. Such reactions are heavily dependent on dissolved oxygen, pH-Eh, and the microbiological conditions, but are generally viewed as being very rapid relative to the flow velocity.

Salinity/Saline Soil: State in soil caused by the presence of soluble salt (ions such as Na, Ca, K, Mg, Cl, SO_4) yielding an electrical conductivity of >2 mS/cm.

Saturated Soil Paste: A particular mixture of soil and water. At saturation the soil paste glistens as it reflects light, flows slightly when the container is tipped, and the paste slides freely and cleanly from a spatula for all soils except those with high clay content.

Saturated Extract: The solution extracted from a soil at its saturation percentage.

Saturation Percentage: The moisture percentage of a saturated soil paste, expressed on a dry-weight basis.

Sodicity/Sodic Soil: State of soil where sufficient exchangeable sodium (ES) is present to affect crop production and soil structure adversely. SAR of the saturation extract >15.

Sodium-Adsorption-Ratio: A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil.

$$SAR = \frac{Na+}{(Ca{+}{+} + Mg{+}{+})/2}$$

where the ionic concentrations are expressed in milliequivalents per liter. See also sodicity.

Till deposits on the Plains are commonly medium to fine textured, stony, non-stratified and well compacted. They were deposited by glaciers and not modified by water and wind action. Topography is undulating to hilly and, in places hummocky. Wetlands are common in depressional areas.

Till deposits in the Foothills and Mountainous Regions are generally thin and frequently mixed with the local bedrock. Usually the till is characterized by a high content of soft coarse fragments and is shallow over weathered bedrock. Slopes are usually very steep.

Total Dissolved Solids/Total Soluble Salts: Total concentration of dissolved (soluble) ions of Na, K, Ca, Mg, Cl, SO_4, HCO_3, CO_3 occasionally NH_4+, NO_3-, PO_4^{2-}.

Weathered Bedrock on the Plains is predominantly silty to clayey textured, slowly to very slowly permeable and has a very low potential for deep percolation. Surface ponding is common after rains and the spring snowmelt. Where the weathered bedrock is of marine origin, sodicity, salinity or high saturation percentages are typical.

FIELD MANUAL

TABLE OF CONTENTS

Page

SYNOPSIS 1

1. SUMP LOCATION EVALUATION 3
Step 1. Field Inspection 3
Step 2. Approval 3
Step 3. Environmental Considerations 3

2. SURFACE WASTE DISPOSAL SITE EVALUATION 6
Step 1. Field Inspection 6
Step 2. Approval 6
Step 3. Environmental Considerations 6
Step 4. Drilling System Options 6

3. DRILLING WASTE CHARACTERIZATION: QUALITY AND QUANTITY 9
Step 1. List Sump Additives 9
Step 2. Determine Sump Volumes 9
Step 3. Sample the Sump 9
Step 4. Analyze the Sump 9
Step 5. Calculate Total Quantities of Constituents 9

4. WASTE DISPOSAL 13
Step 1. Determine Permissible Waste Loading of Each Constituent and Area Required for Surface Disposal 13
Step 2. Determine Depth of Soil Incorporation 15
Step 3. Determine Minimum Acceptable Spread Area 16
Step 4. Select Surface Application Methods 17
Step 5. Select Alternative Disposal Methods 21

5. REFERENCES 32

APPENDX - Checklist for Fieldmen 23

TABLE OF CONTENTS

Page

LIST OF FIGURE

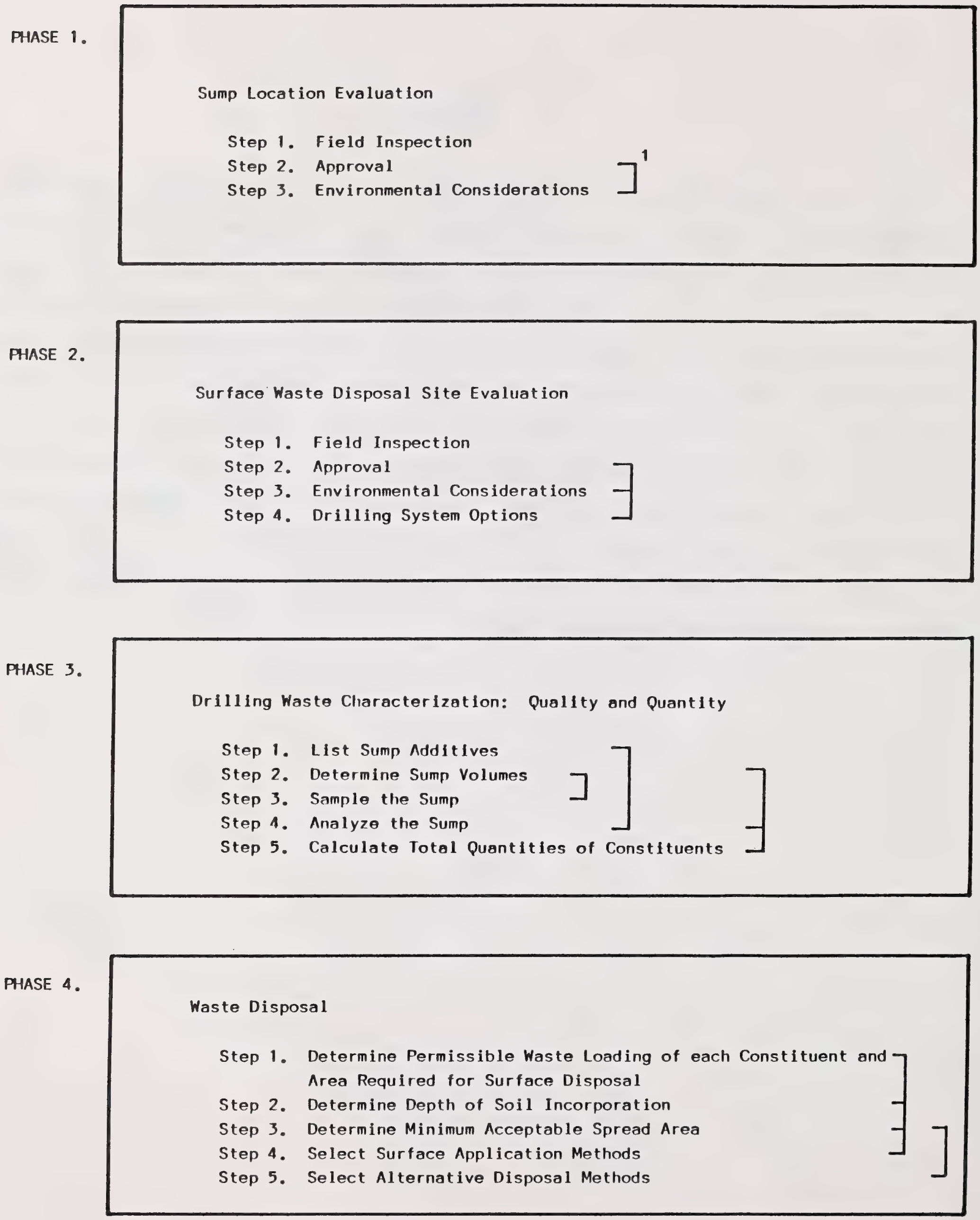
1. Decision Making Chart for Drilling Waste Disposal ... 2

LIST OF TABLES

1.1 Site Suitability Guidelines for Sump Location 4
1.2 Environmental Checklist 5
2.1 Site Suitability Guidelines for Surface Waste Disposal 7
2.2 Environmental Checklist 8
3.1 Guidelines for obtaining Representative Samples 10
3.2 Drilling Waste Analyses Requirements 11
3.3 Calculation Procedures to Determine Sump Contents 12
4.1 Salt Tolerance of Various Plants 18
4.2 Application Methods and Equipment for Liquid and Some Semi-solid Sludges 19
4.3 Methods and Equipment for Application of Semi-solid and Solid Sludges 20

SYNOPSIS

This field manual was prepared in order to assist Government and Industry field staff in selecting methods for environmentally safe disposal of drilling wastes. A decision making flowchart was designed for this purpose. The phases and steps in the chart (Figure 1) and chapters in this manual corresponding to those phases lead to recommended disposal methods based on: Site, waste characteristics and existing Alberta Guidelines. While the phases and steps are presented in sequence, it is also important to have an overall understanding; ideally a waste management plan provided by the driller, prior to initiating inspections. An early appreciation for the types and amounts of constituents to be disposed will assist in establishing how large a disposal area might be needed and how carefully sites are to be examined to ensure minimal negative environmental impact.



PHASE 1.

Sump Location Evaluation

Step 1. Field Inspection
Step 2. Approval
Step 3. Environmental Considerations

PHASE 2.

Surface Waste Disposal Site Evaluation

Step 1. Field Inspection
Step 2. Approval
Step 3. Environmental Considerations
Step 4. Drilling System Options

PHASE 3.

Drilling Waste Characterization: Quality and Quantity

Step 1. List Sump Additives
Step 2. Determine Sump Volumes
Step 3. Sample the Sump
Step 4. Analyze the Sump
Step 5. Calculate Total Quantities of Constituents

PHASE 4.

Waste Disposal

Step 1. Determine Permissible Waste Loading of each Constituent and Area Required for Surface Disposal
Step 2. Determine Depth of Soil Incorporation
Step 3. Determine Minimum Acceptable Spread Area
Step 4. Select Surface Application Methods
Step 5. Select Alternative Disposal Methods

[1] denotes important linkages within phases

Figure 1. Decision Making Chart for Drilling Waste Disposal.

1. SUMP LOCATION EVALUATION

Step 1. Field Inspection

- Review available relevant information about the proposed site including aerial photo examination, soils, geological, hydrogeological and land use maps/reports.
- Investigate the Sump Location and rate each site parameter in accordance with Table 1.1.
- Complete the Sump Location Evaluation Checklist (Page 23).

Step 2. Approval

- Based on the field evaluation, proceed as follows:

  Highly Suitable - approve the site.

  Moderately Suitable - approve the site, subject to use of appropriate, specified management practices to mitigate site limitations.

  Marginally Suitable - approve the site provided that possible consequences of contamination are not serious (see Step 3) and appropriate management is specified to mitigate site limitations. Further field investigation and preparation of a waste handling and site reclamation plan may be required.

  Unsuitable - find an alternative suitable location.

- Document the ratings, conditions of approval, recommended procedures, etc.

Step 3. Environmental Considerations

- Consider the consequences of environmental contamination based on items listed in Table 1.2 and use this subjective evaluation in determining appropriate mitigation measures. There is a trade-off between cost and environmental protection which at this time is left to the judgement of the field officer.
- The officer may request that the client prepare a waste management and reclamation plan that provides for adequate environmental protection, prior to approval.
- Complete the Environmental Checklist for future reference (Page 23).

Table 1.1 Site Suitability Guidelines for Sump Location.

KEY PARAMETERS	Highly Suitable (Acceptable)	Moderately Suitable (Conditionally	Marginally Suitable Acceptable)	Unsuitable (Not Acceptable)	Information Input
WATER					
1. Flooding	None	None	Rarely (1 in 10 years)	Occasional to Frequent	Soil profile characterization Local knowledge
2. Wetness (soil drainage class)	Well to moderately well	Imperfectly	Rapidly if no no groundwater is contaminated	very poorly, very rapidly	Soil profile characterization
3. Distance to Surface Water	>300 m	100-300 m	<100 m	<100 m	Aerial photo Field measurements
4. Groundwater	No Potential for Contamination	No Potential for Contamination	Slight Potential for Contamination	High Potential for Contamination	Boreholes to >4 m
TOPOGRAPHY					
5. Slope (it is assumed the area will be levelled)	0-9%	9-15%	15-30%	>30%	Aerial photo Field measurements
MATERIALS					
6. Soil Texture	C, HC, SiC, SC	L, CL, SiCL Si, SiL	SL, LFS	LS, S, gravel, peat, muck	Hand texture Lab analysis
7. Permeability	Moderately slow to very slow <15 mm/hr	Moderate 15-50 mm/hr	Moderately Rapid 50-150 mm/hr	Rapid to Very Rapid >150 mm/hr	Field permeability measurements Infer from texture
8. Depth to Permeable Bedrock, Sands or Gravels	>3 m	>3 m	2-3 m	<2 m	Boreholes
9. Coarse Fragment Content (% by Volume)	<10	10-30	30-50	>50	Field estimate

Source: Modified from U.S.D.A., 1972 (Suitability for Sewage Lagoons).

Table 1.2 Environmental Checklist.

Features Potentially Affected
  - Groundwater aquifer
  - Watershed - streams, shallow groundwater flow
  - Soils
  - Vegetation (habitat)
  - Wildlife
  - Food chain
  - Adjoining ecosystems
  - Land use - cover, productivity

Seasonal Implications

Impact on people

Cost of future clean-up if necessary

2. SURFACE WASTE DISPOSAL SITE EVALUATION

Step 1. Field Inspection

- Review available relevant information about the proposed site including aerial photo examination, soils, geological, hydrogeological and land use maps/reports.

- Investigate the proposed Spread Site and rate each parameter in accordance with guidelines given in Table 2.1.

- Complete the Surface Waste Disposal Site Evaluation Checklist (Page 24).

Step 2. Approval

- Based on field evaluation, proceed as follows:

  Highly Suitable - approve the site.

  Moderately Suitable - approve the site, subject to use of appropriate management practices to mitigate site limitations.

  Marginally Suitable - approve the site, provided that possible consequences of contamination are not serious (see Step 3) and appropriate management is specified to mitigate site limitations. Further investigation and preparation of a comprehensive land farming plan may be required.

  Unsuitable - find an alternative suitable location or alternative disposal method (see Step 4).

- Document the ratings, conditions of approval, recommended procedures, etc.

Step 3. Environmental Considerations

- Consider the consequences of environmental contamination based on items listed in Table 2.2 and use this subjective evaluation in determining appropriate waste disposal practices.

- The field officer may request that the client prepare a waste management and reclamation plan that ensures adequate environmental protection.

- Complete the Environmental Checklist for future reference (Page 24).

Step 4. Drilling System Options

- As an alternative to employing costly measures to overcome site limitations, consider changing the drilling mud system and additives to minimize any negative environmental impacts. Document any proposed changes on the Waste Disposal Options Checklist.

Table 2.1 Site Suitability Guidelines for Surface Waste Disposal.

KEY PARAMETERS	Highly Suitable (Acceptable)	Moderately Suitable (Conditionally	Marginally Suitable Acceptable)	Unsuitable (Not Acceptable)	Information Input
WATER					
1. Flooding	None	None	Rarely (1 in 10 years)	Occasional and Frequent	Soil profile characterization, Local knowledge
2. Wetness (soil drainage class)	Well to moderately well	Rapidly Imperfectly	Very rapidly	Poorly Very poorly	Soil profile characterization
3. Distance to Surface Water	>300 m	100-300 m	<100 m	<100 m	Aerial photos, Field measurements
4. Groundwater	No Potential for Contamination	No Potential for Contamination	Slight Potential for Contamination	High Potential for Contamination	Boreholes to >4 m
TOPOGRAPHY					
5. Slope	0-5%	5-9%	9-15%	>15%	Aerial photos, Field measurements
MATERIALS					
6. Permeability	Moderate to Moderately Rapid (15-150 mm/hr)	Moderately Slow (5-15 mm/hr)	Slow (1.5-5 mm/hr) Rapid (50-500 mm/hr)	Very Slow (<1.5 mm/hr) Very Rapid (>500 mm/hr)	Field permeability measurements Infer from texture
7. Soil Texture	L, SL, SiL, SCL	SiCL, CL, SC, Si	Slow - SiC, C Rapid - S, LS	Very Slow - HC, muck Very Rapid - gravel, peat	Hand texture Lab analysis
8. Depth to Permeable Bedrock, Sands or Gravels	>1.8 m	1.2-1.8 m	0.5-1.2 m	<.5 m	Boreholes
9. Electrical Conductivity (mS/cm) (horizons affected)	<2	2-4	4-8	>8	EM-38 (not in winter) Lab analysis (A,B,C horizons)
10. Sodium Adsorption Ratio (SAR) (horizons affected)	<4	4-8	8-12	>12	Lab analysis (A,B.C horizons)

Table 2.2 Environmental Checklist.

Features Potentially Affected
- Groundwater aquifer
- Watershed - streams, shallow groundwater flow
- Soils
- Vegetation (habitat)
- Wildlife
- Food chain - animal, human
- Adjoining ecosystems
- Land use - cover, productivity

Seasonal implications - for disposal and re-vegetation

Impact on people

Cost of future clean-up if necessary

3. DRILLING WASTE CHARACTERIZATION: QUALITY AND QUANTITY

Step 1. List Sump Additives

- Prepare a list of additives and quantities used in the drilling and treating processes that end up in whole or in part in the sump. Include wastes such as oil, grease, soap, etc. Indicate amount of fluids/wastes disposed elsewhere if applicable. This information should be provided by the drilling and mud treatment companies.

Step 2. Determine Sump Volumes (Cubic Metres)

- In estimating volumes of "fluids" and "solids" (sludge) layers try to match the respective layers with planned waste handling and disposal techniques such that the portions of a sump that are to be handled and disposed as "fluids" versus "solids" be characterized accordingly. The theoretical distinction between fluid and solid phases is not critical (the lab can provide fluids/solids contents volume and weight basis for each phase).

Step 3. Sample the Sump

- Take samples of the fluids and solids layers that represent the corresponding volumes as determined in Step 2. Use sampling procedures outlined in Table 3.1 (Page 10). When sump treatment is necessary fluids and solids are to be sampled after treatment.

- Record information including location, volume, mud system, smell and appearance of sump, sampling techniques, and operators, and file for future reference.

Step 4. Analyze the Sump

- Submit samples for analyses listed in Table 3.2 (Page 11) to a reliable commercial laboratory. Request lab to report results in kg/m^3 where appropriate. The field officer should specify planned disposal techniques, that is, as submitted, dried, or diluted and if there are changes by dilution or concentration make appropriate corrections.

Step 5. Calculate Total Quantities of Constituents

- If sump volumes (m^3) of each phase which the sample represents are provided, the laboratory personnel can calculate total quantities of constituents in the sump (see Table 3.3). This input is needed in determining spread rates.

Table 3.1 Guidelines for Obtaining Representative Samples.

Sump Fluids (based on ERCB ID-OG75-2)

1. Divide the sump into six segments and then obtain samples near the surface, middle and bottom of each segment. In this way 18 samples will be obtained to form a single composite sample.

2. The minimum composite sample size is 2 quarts collected in a glass or plastic container.

Sump Solids (suggested procedure, field testing needed)

1. Divide the sump into six segments and obtain samples from each segment. Try to obtain a representative mixture from top to bottom of solids in each segment. Combine the 6 samples to form a single composite sample.

2. The minimum composite sample size is 2 litres collected in a glass or plastic container.

Table 3.2 Drilling Waste Analyses Requirements.

REQUIRED BY ERCB (INTERIM DIRECTIVE ID-OG75-2)

CONSTITUENT - FLUIDS	ACCEPTABLE CONCENTRATION* For Disposal in the Environment
Total Dissolved Solids	<4,000 mg/l
Chlorides (Cl)	<1,000 mg/l
Sulphates ($SO_4=$)	<2,000 mg/l
pH	5.5 - 8.5
Toxicity	pass trout or microtox test

RECOMMENDED ADDITIONAL ANALYSES

FLUIDS AND SOLIDS	SOLIDS
Minimum Required	
Soluble Calcium (Ca)	Bulk Density
Soluble Magnesium (Mg)	Field Moisture Percentage
Soluble Sodium (Na)	Saturation Percentage
Soluble Potassium (K)	
Soluble Carbonate (CO_3)	
Soluble Bicarbonate (HCO_3)	
Nitrate Nitrogen (NO_3)	
Electrical Conductivity (EC)	
Sodium Adsorption Ratio (SAR)	
Optional	
Hot water soluble Boron (B)	Particle Size Analysis (texture)
Total Cadmium (Cd)	Exchangeable Cations
Total Chromium (Cr)	Calcium
Total Copper (Cu)	Magnesium
Total Mercury (Hg)	Sodium
Total Nickel (Ni)	Potassium
Total Lead (Pb)	
Total Zinc (Zn)	

* If concentration exceeds these limits treat to reduce or dispose by alternate method.

Table 3.3 Calculation Procedures to Determine Sump Contents.

FLUIDS

Waste content of sump "fluids" is calculated by multiplying the concentration (measured by lab) by the volume (estimated in field).

kg constituent = mg/l (or ppm) x 0.001* x volume (m^3)**

* mg/l x 0.001 = kg/m^3
** 1,000 m^3 is approximately 6,000 barrels, therefore, if sump volume is 1,000 m^3, then constituent in kg = concentration in mg/l (or ppm)

SOLIDS

Dominantly fluid:*
total waste = waste in fluid (ignore solid)

Wet solid sample:**
total waste = waste in fluid (analyze as fluid) + waste in solid (analyze as soil)

Dry solid sample:**
total waste = waste in solid (analyze as soil)

* calculations same as for fluids
** calculations complex, request laboratory to provide total waste (fluid plus solid, or solid) in kg per m^3, then m^3 x kg/m^3 equals kg of constituent.

Examples

- 4,000 mg/l TDS in sump fluids totalling 1,000 m^3 equals 4,000 kg of salt to be disposed;
- 4,000 mg/l TDS in 500 m^3 of sump fluids equals (4,000 x 500 x 0.001) kg or 2,000 kg of salt.
- 10,000 mg/l TDS in 50 m^3 of sump solids equals (10,000 x 50 x 0.001) kg or 500 kg of salt.

4. WASTE DISPOSAL

Step 1. Determine Permissible Waste Loading of Each Constituent and Area Required for Surface Disposal

Existing Standards

- Currently, there are standards for four parameters and the following rates of disposal on land are permitted (wastes must not be disposed into surface waters):

chloride	$\leq$ 450 kg/ha	pH	5.5 - 8.5
sulphate	$\leq$ 230 kg/ha	toxicity	pass trout or microtox test

Salts (Salinity)

- To determine permissible salt loading the maximum allowable soil salinity (EC) level, background soil salinity and sensitivity of the vegetation must be considered. As a guide, in a 20 cm layer of soil the addition of about 1,000 kg/ha (±25%) of salt amounts to an increase in EC of 1 mS/cm. Salt tolerance of various plants is given in Table 4.1. Calculation procedures and data requirements for comprehensive analysis are complex: if a large amount of salts must be disposed and a sizeable area is to be affected, a specialized study is recommended. In practice, if chlorides and sulphates are within acceptable limits, there should not usually be salinity problems.

Sodium

- Permissible sodium loading depends on soil salinity, background sodicity and tolerable sodicity levels. As a guide, if the sodium adsorption ratio (SAR) of applied wastes is less than 10 and final soil EC <4 mS/cm, then soil sodicity should not become limiting. If SAR of wastes exceed 10 then soil sodicity problems can be expected and treatment to reduce SAR is needed or specialized investigation to determine whether higher levels are tolerable is recommended.

  A comprehensive analysis of soil and waste qualities and amounts is needed to estimate the SAR of the final mixture of soils and wastes. Addition of calcium nitrate, calcium chloride or gypsum may be needed to reduce SAR, provided other problems do not arise. A detailed analysis is needed by a specialist in order to determine appropriate amounts and amendments.

Metal Loading

- Maximum permissible cumulative metal loadings to soils established for sewage disposal are tentatively recommended for drilling waste disposal. Research is urgently needed to confirm or modify the levels. The behavior of each element is determined by many factors, hence, the limits shown following are a guide only. In any instance where levels approach or exceed these limits conduct detailed analyses - safe loadings may be much higher or lower.

Maximum Permissible Cumulative Metal Loadings to Soils (kg/ha)

Soil Texture[1]	B[2]	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Medium to Fine	10	1.5	100	200	0.5	25	100	300
Very Fine	7.5	1.1	75	150	0.4	19	75	200
Coarse	5	0.8	50	100	0.2	12	50	150
Sands, gravels, organic soils - not acceptable								

Source: Alberta Environment, 1982.

[1] Other site characteristics must also be considered.
[2] Hot water soluble; other elements based on total quantities.

Solids

- Permissible solids loading is dependent on chemical and physical properties of the mud. In saline muds, salinity will be most limiting and will govern spread rates. For disposal of salt-free muds, use the following guidelines; and carefully record all procedures, rates of application, problems, and results for future reference.

Surface Crusting and Clod Formation

- Submit separate representative samples (10 kg each) of mud and soil to a laboratory to test modulus of rupture on various mixtures of mud and soil, e.g. 20%, 40%, 60% mud. Specify to the lab the expected moisture content of the mud when it is to be disposed so that the lab can provide an appropriate application rate in m^3/ha or thickness.

  the modulus of rupture is an index of the strength of materials and is applied for evaluating the cohesion of dry soils, particularly as related to surface crusting and clod formation. Modulus of rupture values are useful in assessing the germination and emergence potential of various materials.

  As a guide, the following ratings may be used:

	Good	Fair	Poor	Unsuitable
Modulus of rupture (millibars)	<150	150-250	250-500	>500

  It is desirable that the final rating be "good".

Soil Texture

For fine soils: Topsoils - heavy clays, clays, silty clay loams, clay loams, sandy clays, sandy clay loams; Subsoils - heavy clays, clays, silty clay loams.

- do not add mud if the mud is finer textured than the soil.
- add no more than 25% volume, i.e. 5 cm mud/20 cm mud and soil - if the mud is the same texture as the soil.
- add as much as 50% volume, i.e. 10 cm mud/20 cm mud and soil - if the mud is coarser than the soil.

For medium and coarse soils: silts, silt loams, loams, sandy loams, loamy sands and sands.

- add as much as 50% volume, i.e. 10 cm mud/20 cm mud and soil but do not make the final mixture finer than silty clay loam, clay loam or sandy clay loam.

Step 2. Determine Depth of Soil Incorporation

In addition to area and quantity of waste, the depth of soil incorporation must be considered. Two approaches are practiced at this time and both are considered to be safe.

Land spreading, assumes that all wastes would be applied on the surface and, in the worst case, retained in a 20 cm layer. This thickness is based on incorporation with industrial or heavy duty farm machinery, and for many soils this approximately matches the A horizon (including LFH, Ah, Ae, Ap). When organic constituents are significant, this method is recommended as biological degradation is enhanced at the surface.

Squeezing, entails initially removing topsoil/litter, then spreading of wastes on the B horizon along with ripping to enhance infiltration, and finally recapping with uncontaminated A horizon material. Using ripping equipment it is feasible to incorporate wastes to a 40 cm to 60 cm depth, permitting doubling or tripling of salt (cations and anions) application rates while maintaining constituent levels within permissible limits. Capping with "clean" topsoil provides a rooting medium for a vegetative cover to get established. In time natural leaching should move soluble salts downward thereby providing a good rooting medium. Disadvantages of this approach include restricted biological decomposition (therefore, deep incorporation is not recommended for organic-rich wastes), destruction of subsoil structure and compaction (winter operations appear to be less harmful), downslope migration of salts, and potential for groundwater contamination. Advantages include preservation of a suitable topsoil for revegetation and erosion control, reduced risk of contaminant runoff once the topsoil is replaced, and a smaller disposal area if incorporating to 40 or 60 cm (important in forest lands).

Step 3. Determine Minimum Acceptable Spread Area

Summarize spread areas required for each mud component (Step 1) and depending on depth of incorporation (Step 2) determine the minimum area required to maintain good soil quality. An example follows:

> Dividing the quantity of salt to be disposed by the permissible waste loading for a given constituent yields the area needed for disposal:
>
> AREA NEEDED (ha) = QUANTITY (kg) / PERMISSIBLE LOADING (kg/ha)
>
> Example: Quantity of Wastes: 4,000 kg of salts
> 1,000 kg of chlorides
> 2,000 kg of sulphates
>
> Permissible loading: 2,000 kg/ha of salts for EC <2
> 450 kg/ha of chlorides
> 230 kg/ha of sulphates
>
> Area needed: for salts $\frac{4{,}000 \text{ kg x ha}}{2{,}000 \text{ kg}} = 2$ ha
>
> for chlorides $\frac{1{,}000 \text{ kg x ha}}{450 \text{ kg}} = 2.2$ ha
>
> for sulphates $\frac{2{,}000 \text{ kg x ha}}{230 \text{ kg}} = 8.7$ ha
>
> The area needed is dictated by the most limiting factor, in this case, sulphate, therefore 8.7 ha is required for spreading.

Examine opportunities for treating the mud to increase application rates and reduce the spread area. This will be determined by technical, economic and practical considerations. If the spread area is too large: an alternative disposal method is needed (see Step 5).

Step 4. Select Surface Application Methods

The criteria for selection of application systems and equipment are dependent upon several factors:

- the form of the sludge (fluid, semi-solid or solid)
- the quantity
- the area application rate
- the frequency of application (one time, several times)
- time of year
- topography of area

Application methods and equipment for fluid and some semi-solid municipal sludges are summarized in Table 4.2. Surface application is performed either by irrigation or tank vehicle. A fixed irrigation system is best suited where sludges are applied regularly. The tank truck provides flexibility in where to haul and where to apply the sludge. The use of a pumped discharge on the tank allows discharge over a wider area or from a roadway. Subsurface injection is considered if public nuisance from sludge application is a possibility.

Methods and equipment for application of semi-solid and solid sludges are summarized in Table 4.3. The most economical methods for drilling mud sludges are probably surface application by tank vehicle of fluids or spreading of semi-solid sludges.

Table 4.1 Salt Tolerance of Various Plants.

LOW <1500 ppm* (EC <2)	MODERATE 1500-3000 ppm* (EC 2-4)	HIGH >3000 ppm* (EC >4)
	CONIFEROUS SPECIES**	
Red Pine	Tamarack	Jack Pine
Scotpine	Norway Spruce	Mugo Pine
White Pine	Juniper	Black Spruce
Colorado Spruce	White Cedar	
Balsam Fir		
	DECIDUOUS SPECIES	
Manitoba Maple	Birch Spp.	Russian Olive
Dogwood	Buckthorn	Honeysuckle
Spirea	Forsythia	Lilac
		Caragana
		Chokecherry
		Mayday

LOW (EC <4)	MODERATE (EC 4-10)	HIGH (EC >10)
	GRASSES/FORAGES	
Timothy	Perennial Ryegrass	Western Wheatgrass
Meadow Foxtail	Bromegrass	Canadian Wild Rye
Clvoer	Tall Fescue	Bermuda Grass
Sweet Clover	Reed Canary Grass	Salt Grass
Alsike Clover	Alfalfa	
Red Clover	Sweet Clover	
	FIELD CROPS	
Peas	Corn Oats	Barley
Beans	Canola Rye	
Flax	Wheat	

* concentration in saturated extract.
** some exotic species are included because they are used in Alberta as ornamentals or for shelterbelts.
*** note salinity limits differ for corresponding classes.

Source: Edwards, 1985; confiers, deciduous trees, shrubs.
Alberta Agriculture, 1985; grasses, forages, field crops.

Table 4.2 Application Methods and Equipment for Liquid and Some Semi-solid Sludges.

Method	Characteristics	Topographical and Seasonal Suitability
SURFACE APPLICATION:		
Irrigation:		
Spray (sprinkler)	Large orifice required on nozzle; large power and lower labor requirement; wide selection of commercial equipment available; sludge must be flushed from pipes when irrigation completed.	Can be used on sloping land; can be used year-round if the pipe is drained in winter; not suitable for application to some crops during growing season; odor (aerosol) nuisance may occur.
Overland flow	Used on sloping ground with vegetation with no runoff permitted; suitable for emergency operation; difficult to get uniform area application.	Can be applied from ridge roads.
Tank truck	Capacity 500 or more than 2,000 gal; large volume trucks will require flotation tires; can use with temporary irrigation set-up; with pump discharge can spray from roadway onto field.	Tillable land; not usable with row crops or on soft ground.
Farm tank wagon and tractor	Capacity, 500 to 3,000 gal; larger volume will require flotation tires; can use with temporary irrigation set-up; with pump discharge can spray from roadway onto field.	Tillable land; not usable with row crops or on soft ground.
SUBSURFACE APPLICATION		
Flexible irrigation hose with plow furrow or disc cover	Use with pipeline or tank truck with pressure discharge; hose connected to manifold discharge on plow or disc.	Tillable land; not usable on wet or frozen ground.
Tank truck with plow furrow cover	500 gal commercial equipment available; sludge discharged in furrow ahead of plow mounted on rear of 4-wheel-drive truck.	Tillable land; not usable on wet or frozen ground.
Farm tank wagon and tractor:		
Plow furrow cover	Sludge discharged into furrow ahead of plow mounted on tank trailer, application of 170 to 225 wet tons/acre; or sludge spread in narrow band on ground surface and immediately plowed under, application of 50 to 125 wet tons/acre.	Tillable land; not usable on wet or frozen ground.
Subsurface injection	Sludge discharged into channel opened by a tillable tool mounted on tank trailer; application rate 25 to 50 wet tons/acre; vehicles should not traverse injected area for several days.	Tillable land; not usable on wet or frozen ground.

Source: Torrey, 1979.

Table 4.3 Methods and Equipment for Application of Semi-solid and Solid Sludges.

Method	Characteristics
Spreading	Truck-mounted or tractor-powered box spreader (commercially available); sludge spread evenly on ground; application rate controlled by over-the-ground speed; can be incorporated by discing or plowing.
Piles or windrows	Normally hauled by dump truck; spreading and levelling by bulldozer or grader needed to give uniform application; 4 to 6 inch layer can be incorporated by plowing.

Source: Torrey, 1979.

Step 5. Select Alternative Disposal Methods

The following are alternatives to surface disposal but existing field tested procedures that are environmentally safe have not been developed to the point where clear recommendations can be given. For planning waste disposal techniques the mud systems and additives to be used should be evaluated in terms of their environmental implications, and the best overall approach should be used considering drilling performance, economics and environmental impact.

Burial and Trenching - These practices are discouraged (not allowed by ERCB) because of low degradative potential, possible formation of anaerobic decomposition products which are uncontrollable, and potential contamination of groundwater. Research is underway to develop techniques to enhance subsurface decomposition -- this could lead to new approaches to burial and trenching.

Treatment - Various treatments: separation, detoxification, pH adjustment, and others are practised to make drilling waste fluids meet standards for surface disposal. However, the solids portion has largely been ignored to date. Research is needed to characterize the solids and to develop appropriate procedures for treating and handling them.

Solidification - The aim of solidification is to render the mud and cuttings compounds insoluble and, as such, environmentally safe for burial. Short term results of research are promising but there is skepticism as to how long the solidification will last.

Off-site - Establishment of special waste disposal or treatment facilities, disposal into disposal wells and recycling of wastes eliminate the on-site environmental hazards and should be encouraged provided an environmental problem is not created elsewhere.

Utilization - Processing or treatment of wastes in a manner that makes them a desired product rather than a waste must be encouraged. Examples include use of fines to improve physical characteristics of sandy soils (example, Wainwright area), addition of K to K-deficient soils (example, Bonnyville area), and addition of calcareous products to increase pH of acidic soils (example, areas in northern Alberta). Attention is needed to ensure that noxious elements, sterilants, etc. are not added to the waste thereby causing other problems A "systems" approach considering drilling through to final use of the product is needed and research in this area should be encouraged. Promising opportunities for waste utilization should be explored and documented.

5. REFERENCES

Alberta Agriculture, 1985. Soil erosion and salinity surveys: a procedures manual.

Alberta Environment, 1982. Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands.

Edwards, I., 1985. Salt Effects on Vegetation. Paper presented at Seminar/Workshop on Gel and Saline Based Drilling Wastes, Edmonton, Alberta, April 24, 1985, sponsored by Alberta Energy and Natural Resources.

Pedology Consultants, Piteau Engineering Ltd., HydroQual Consultants Inc., 1986. Disposal of Wastes from Drilling Systems on the Public Lands of Alberta. Prepared for Alberta Forestry, Lands and Wildlife and Alberta Environment. Edmonton.

Torrey, S. (Ed.), 1979. Sludge Disposal by Landspreading Techniques. Noyes Data Corporation. Park Ridge, New Jersey, U.S.A.

U.S.D.A., 1972. Guide for Interpreting Engineering Uses of Soils.

CHECKLIST FOR FIELDMEN

1. SUMP LOCATION EVALUATION

1.1 Sump Location Classification (refer to Table 1.1)

Date:

LSD SEC TWP RGE W

Evaluated by:

OPERATOR(S)

	Rating[1]				
Key Parameters	H.S.	Mod.S	Mar.S	U	Comments
1. Flooding					
2. Wetness					
3. Distance to Water					
4. Groundwater					
5. Slope					
6. Texture					
7. Permeability					
8. Depth to permeable strata					
9. Coarse fragment content					

Most Limiting Rating and Parameter(s)

Recommendations, conditions for approval, etc.

[1] H.S. = Highly Suitable Mod.S = Moderately Suitable Mar.S = Marginally Suitable U = Unsuitable

1.2 Environmental Consequences of Contamination by Sumps

	Problems Anticipated			
Feature	None	Signi	Major	Comments
Groundwater aquifer				
Watershed				
Soils				
Vegetation				
Wildlife				
Food chain				
Adjoining ecosystems				
Winter				
Spring				
Summer				
Fall				
Land use (returned)				
Land use (changed)				
Sparse settlement/use				
Moderate settlement/use				
Intensive settlement/use				
Clean-up costs				

Recommendations

2. SURFACE WASTE DISPOSAL SITE EVALUATION

LSD____ SEC____ TWP____ RGE____ W____
OPERATOR(S) ____________________
DATE ____________________
EVALUATED BY ____________________

2.1 Surface Waste Disposal Classification (refer to Table 2.1)

	Rating[1]				
Key Parameters	H.S.	Mod.S	Mar.S	U	Comments
1. Flooding					
2. Wetness					
3. Distance to Water					
4. Groundwater					
5. Slope					
6. Permeability					
7. Texture					
8. Depth to permeable strata					
9. Electrical Conductivity					
10. Sodium Adsorption Ratio					

Most Limiting Rating and Parameter(s) ____________________
Recommendations, conditions, management practices, etc. ____________________
____
____

[1] H.S. = Highly Suitable Mod.S = Moderately Suitable Mar.S = Marginally Suitable
U = Unsuitable

2.2 Environmental Consequences of Contamination by Surface Disposal

	Problems Anticipated			
Feature	None	Signi	Major	Comments
Groundwater aquifer				
Watershed				
Soils				
Vegetation				
Wildlife				
Food chain				
Adjoining ecosystems				
Winter				
Spring				
Summer				
Fall				
Land use (returned)				
Land use (changed)				
Sparse settlement/use				
Moderate settlement/use				
Intensive settlement/use				
Clean-up costs				

Recommendations ____________________
____
____
____

2.3 Waste Disposal Options

Proposed Mud System		Major Additives (proposed)
Fresh water		
Salt water		
Invert mud		
Other		

3. WASTE CHARACTERISTICS

3.1 Sump Constituents

Mud System		Additives (amounts)
Fresh water	____	________________________
Salt water	____	________________________
Invert mud	____	________________________
Other	____	________________________
		________________________

3.2 Sump Volumes

Fluids ______________ m^3, ______________ barrels
Solids ______________ m^3, ______________ barrels

3.3 Sampling Procedures

Sampling Date: ________________________
Sampled By: ________________________
Submitted To: ____ ERCB or ____ Commercial Lab (Name)________________

Sampling Design

Liquids:	____________	composite(s) of	____________	subsamples
	____________	point	____________	mixed
	____________	grid	____________	other (specify)
	____________	before treatment	____________	after treatment
Solids:	____________	composite(s) of	____________	subsamples
	____________	point	____________	mixed
	____________	grid	____________	other (specify)
	____________	before treatment	____________	after treatment

Sampling Devices
Liquids: ______________________ Solids: ______________________

3.4 Analyses Procedures

____ Routine as per ERCB - Interim Directive ID-OG75-2 (Table 3.2)
____ Additional Minimum (Table 3.2) specify:________________________
____ Additional Optional (Table 3.2) specify:________________________
____ Other specify:________________________

3.5 Quantities of Constituents

Specify separately for liquids and solids where appropriate.

Constituent	kg/m^3	x	m^3	=	kg	Parameter	
Ca	________	x	________		________	Texture	____________
Mg	________	x	________		________	pH	____________
Na	________	x	________		________	EC	____________
K	________	x	________		________	SAR	____________
						Toxicity	____________
Cl	________	x	________		________	% moisture	____________
SO4	________	x	________		________	Saturation %	____________
TDS	________	x	________		________	Bulk density	____________
Other (list)							
____________	________	x	________		________		
____________	________	x	________		________		
____________	________	x	________		________		

4. WASTE DISPOSAL

4.1 Permissible Waste Loading for Surface Disposal

Background Soil Conditions

	Topsoil(A)	Subsoil(B)		
Texture			Soil classification	
Depth			Parent Material	
pH			Series	
EC			Drainage	
SAR			Topography (slope)	
Other			Land Use	
			Vegetative Cover	
			Other	

Maximum Spread Rate

	Parameter	Quantity		Maximum		Area	
Fluids	Salts		kg divided by	*	kg/ha =		ha
	SAR			8			
	Cl		kg divided by	450	kg/ha =		ha
	SO4		kg divided by	230	kg/ha =		ha
	Other:						
			kg divided by		kg/ha =		ha
			kg divided by		kg/ha =		ha
			kg divided by		kg/ha =		ha

Most limiting constituent ______

Recommended spread area ______ ha

Solids Mud ______ vol.m^3 divided by $\frac{\text{depth cm}}{10^6}$ = ______ ha

	Parameter	Quantity		Maximum		Area	
	Salts		kg divided by	*	kg/ha =		ha
	SAR						ha
	Cl		kg divided by		kg/ha =		ha
	SO4		kg divided by		kg/ha =		ha
	Other:						
			kg divided by		kg/ha =		ha
			kg divided by		kg/ha =		ha
			kg divided by		kg/ha =		ha

Most limiting constituent ______

Metal loading problem ______ yes ______ no ______ unknown

If solids and liquids can be spread in same area: define conditions.

* depends on salt composition and final desired EC.

4.2 Depth of Soil Incorporation

______ cm depth incorporated, ______ adjusted spread area

4.3 Minimum Spread Area

______ ha based on maximum spread rate and incorporation to ______ cm depth

4.4 Waste Application

		Equipment	Date
Method	- Fluids		
	- Solids		
Incorporation	- Fluids		
	- Solids		

4.5 Alternative Disposal Methods

Specify: ______

N.L.C. - B.N.C.
3 3286 07993483 8